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Petrologic aspect of pericline twinning in albites of igneous rocks

ABSTRACT: Secondary albites ($\sim An_0$) and primary feldspars replaced by them in volcanic rocks and granitoids have been studied by means of microscopic methods. Particular attention has been given to albite twins and their origin, conditions of origin and differentiation depending on the kind of feldspar replaced by albite. Twinnings of two genetic types have been found to occur in albites, namely: the relicts (*i.e.* inherited after earlier feldspars) of normal habit of lamellae, and growth twinnings of chessboard habit of twin-bands. The relict twinnings occur in albites developed at the expense of primary plagioclases and rarely of potassium feldspars. A method has been established for the determination of the primary plagioclase composition on the basis of the position of the relict pericline composition plane in secondary albite taking into account the (*Al, Si*)-ordering state in plagioclase structure of volcanic and plutonic rocks. An extremely rare case has been found of Ala-A twinning in which the rhombic section 0kl is the composition plane (the case theoretically anticipated by Franke, 1920). Chessboard twinning characterizes albites developed at the expense of potassium feldspars, and only occasionally at the expense of plagioclases. They show important differences in their form depending on the kind of primary feldspar. The method of recognition of secondary albites and for the determination of the primary composition of plagioclase on the basis of the position of the pericline composition plane, as used in this paper, implies that the albitization processes in igneous complexes are much more frequent than was hitherto supposed, and the share of primary alkaline rocks — mainly the sodium ones — in the earth's crust is smaller than previously assumed.

INTRODUCTION

It has been a long-known fact that pure or anorthite-poor albites are characterized by a particularly inconstant position of the pericline composition plane (*PCP* [1]), whereas in the remaining plagioclases the

[1] This abbreviation denotes the pericline composition plane farther in the text.

orientation of that plane changes usually consequently with the change of *An*-content. For almost 100 years various σ[2] angles (from 0° up to 37°) have been reported for such albites, the angle being measured on the {010}-pinacoid between the traces of the *PCP* and the cleavage (001). Some time ago this fact even resulted in a view that the value of σ in acid plagioclases cannot be used as a basis for determination of the *An*-content (Duparc & Reinhard 1924; Reinhard 1931).

According to the prevailing opinion, the variable position of *PCP*, called the rhombic section, in albites depends chiefly on (*Al*, *Si*)-ordering which is controled by its crystallization temperature (Smith 1958, 1962; Barth & Thoresen 1965; Donnelly 1963; Barth 1969). This view is based on the studies of the effect of temperature on cell angles of albite with which the value σ is connected functionally. The calculated σ angles gave, indeed, a very similar range of variability to that in natural albites of $< An_5$. The author's investigations, however, seem to suggest that the position of *PCP* in secondary albites of igneous rocks is chiefly controled by the composition of the primary plagioclase.

Common lack of correlation between the σ value and the composition has been found mainly in low-temperature albites, the so-called periclines from Alpine veins, and in albites from pegmatites. So far, little is known about position of *PCP* in the rock-forming albites, although such feldspars are common components of many igneous and epimetamorphic rocks. It is argued below that the almost-pure albites of igneous rocks are as a rule the products of sodium metasomatism of plagioclases of various *An*--content. Such pseudomorphs are characterized by a position of the *PCP* as variable as it is in the above-mentioned vein albites.

It was found long ago that secondary albites developing at the expense of plagioclases in volcanic rocks inherit their twin structure (Nowakowski 1957, 1967, 1968, 1969; Reverdatto 1960; Rusinov 1965, 1968). Hence, the supposition of Laves & Schneider (1956), that the Alpine periclines characterized by σ_{PCP} angles too small for pure albites are pseudomorphs after oligoclases, turned out to be correct. Smith (1958, 1962) was also right that albite replacing more basic plagioclase may preserve its *PCP* unchanged. Hence, it becomes feasible to determine the primary composition of plagioclase on the basis of features of Pericline--twinned secondary albite.

The results of investigations of secondary albites and primary plagioclases presented in this paper are based on an abundant and petrographically diversified collection of over 1500 samples. Those are mostly Permian and Upper Carboniferous volcanic rocks, and in part old Paleozoic spilites and keratophyres from the Sudetes. A large collection of Cambrian volcanic rocks, Caledonian dykes, and Salairian granitoids

[2] Positive values of σ are given in the text without "+", negative ones with "—" sign.

from Western Mongolia brought by the Polish Geological Expedition 1961—1964 (S. Kozłowski 1969; Nowakowski 1969) has been also examined.

Acknowledgements. The discussed rock material was supplemented by samples of Permian volcanic rocks from boreholes situated in the Fore-Sudetic Monocline and Western Pomerania. Besides, the author used other samples of various igneous rocks from the Sudetes, being kept in the collections of Professor K. Smulikowski, Professor H. Teisseyre, Dr. Ł. Karwowski, Dr. A. Kozłowski, Dr. W. Ryka, Dr. R. Sałaciński, Dr. A. Teisseyre, Dr. J. Teisseyre and W. Olszyński M. Sc. To all these persons the author wishes to express his most sincere thanks. Similar thanks are also due to Docent J. Ansilewski for discussions on the feldspar problems.

POSITION OF PERICLINE COMPOSITION PLANE AND OF THE RHOMBIC SECTION IN PLAGIOCLASES

Vom Rath (1876) named the pericline composition plane in plagioclases the rhombic section and revealed that it is an irrational plane of the [010] zone, the position of which depends on the *An*-content. The maximal variability range of the σ angle which characterizes the position of that plane in plagioclases $Ab_{100}An_0$—Ab_0An_{100} is 53° (Fig. 10).

The σ value is a function of lattice angles which allow the theoretical establishment of the position of the rhombic section *RS* [3]. According to calculations by Schmidt (1919), this value for pure albite is 40°. The σ value calculated on the basis of the relation given in Fig. 10 does not always coincide with the observed one expressed as the *PCP*. A cause of this discrepancy is a change of cell angles after establishment of the Pericline twins. Particularly striking differences have been reported for pure albites. Laves & Schneider (1956) noticed, for example, that the σ_{PCP} angle in the Alpine periclines is 9—10°, whereas the theoretically calculated σ value of the *RS* plane in pure albite is 33°. Thus the calculated σ_{RS} angle for ordered albites which are most common in nature is approximately constant, whereas the measured σ_{PCP} values may vary within a considerable range (Table 1). The presented σ_{PCP} values of 29° and 37°, close to the theoretically established σ_{RS} angle in the ordered albite, refer, in the present author's opinion, to the primary albites. All the lower σ_{PCP} values, on the other hand, refer to albite pseudomorphs after plagioclases of various compositions.

It has been long believed that the position of the *RS* plane in plagioclases was controled by *An*-content only. Later on, Duparc & Reinhard (1924) and Reinhard (1931) questioned the validity of that idea for acid plagioclases, and Barth (1928) for the entire plagioclase series. Only during the last twenty years has there been progress in the understanding of the

[3] The rhombic section will be referred to as the *RS* in the text.

Table 1

Variability of σ-angle of pericline composition plane in albites ~An_0 of various derivation and probable composition of primary plagioclase

No.	Occurrences	σ°-PCP*	Primary composition An**	References
	Albites of veins:			
1	La Fibbia, Switzerland	7.5 - 11	32 - 26	Lewis, 1915
2	Swiss Alps /periclines/	9 - 10	29 - 27	Laves & Schneider, 1956
3	Pfunders, Tirol /pericline/	13	23	vom Rath, 1876
4	Not given	13	23	Becke, 1906
5	Somero, Finland	20	15	Wiik, 1878
6	Kragerö, Norway	22	13	vom Rath, 1876
7	Kragerö, Norway	29	4	Schmidt, 1919
8	Not given	37	0	Wülfing /see Reinhard, 1931/
9	Torsvik, Norway /albite veins in microcline/	37	0	Barth, 1928
10	Not given /specimens from the Cambridge Museum/	0 - 20	/?/ - 15	Smith, 1958
11	Not given	0 - 37	/?/ - 0	Reinhard, 1931
	Albites of volcanic rocks:			
12	Virgin Islands /quartz keratophyres/	0, <u>2</u>, 6	/?/, 35, 19	Donnelly, 1963
13	Sudetes and Western Mongolia /rhyolites, rhyodacites, dacites, keratophyres/	<u>0</u> - <u>5.5</u>	42 - 21	Nowakowski } see Tabs. 2-4
14	Sudetes and Western Mongolia /latites, trachybasalts, basalts/	-3, <u>0</u>	57, /?/	Nowakowski } see Tabs. 2-4
	Albites of granitoids:			
15	Sudetes, Western Mongolia and Niger	0, 5 - <u>20</u>, 25, 30, 37	/?/, 37 - 15, 10, 2, 0	Nowakowski, see Tab. 5 and Figs 12, 14

* The most frequent σ-values underlined.

** Established on the basis of σ-PCP angle in albite. The angle σ = 0° for feldspars cited in the references was not used as there was no certainty whether it was the PCP or the Acline-A twinning composition plane.

Albite data at Nos. 3, 5 and 6 after Schmidt (1919)

factors governing the position of the *RS* plane (Laves & Schneider 1956; Smith 1958, 1962; Barth & Thoresen 1965; Bambauer, Eberhard & Viswanathan 1967; Starkey 1967; Barth 1969). According to Smith (1958, 1962), the position of the *RS* depends mainly on the *An*-content and the degree of (*Al*, *Si*)-ordering, the influence of the latter being most clearly expressed in albite An_0 (Fig. 10). The influence of other factors (such as the presence of potassium in the plagioclase lattice) is of little importance according to Smith (1958, 1962). The role of pressure in this respect is yet unknown.

Smith (1958) presumed that the *PCP* is parallel to the theoretical *RS* at the moment of establishment of twins. The parallelism of these planes is preserved as long as the chemical composition of plagioclase and its structural state remain unaltered, otherwise such changes must result in a change in the lattice angles: the *RS* plane must change its position, whereas the *PCP* may retain its previous orientation unless a given plagioclase did not recrystallize. A recrystallization process connected with the simultaneous development of Pericline twinning must lead to the origin of a new *PCP*, the orientation of which will be concordant with the actual *RS* plane.

An opinion prevails that in albites very large deviations in the positions of the *PCP* and the *RS* planes are due to changes of structural state (Barth & Thoresen 1965; Barth 1969). Only Laves & Schneider (1956) did not admit such a possibility for the Alpine periclines. Smith (1958, 1962) did not exclude changes in the composition as a secondary cause of *RS* variability, but believed compositional changes in plagioclases to be probably rare, particularly in igneous plagioclases, and consequently he assumed that changes of ordering state were the main controling factor.

PETROGRAPHY OF ALBITIZED IGNEOUS ROCKS

General petrographic characteristics are presented below (Figs 1 and 3—4) for the Carboniferous and Permian volcanic rocks mainly from the Sudetes, and of the Cambrian and Caledonian volcanic rocks of Western Mongolia and the Variscan granitoids of the Strzegom-Sobótka Massif situated in the Sudetic Foreland. Processes of autometasomatic albitization of plagioclases and chloritization of pyroxenes and biotite played an important role in the posteruptive evolution of the volcanic rocks. The plagioclases of some portions of the granitoids were also subjected to strong albitization. Unlike the plagioclases, the potassic feldspars both in the volcanic and in the granitoid rocks have undergone no significant albitization.

The rock in question are very favourable for the recognition of the development of secondary albites and their twinnings, as the relicts of primary plagioclases are here preserved. In some cases the albitized rocks pass gradually into almost unaltered rocks. The metasomatism of the Sudetic and Mongolian volcanic rocks acted under static conditions, and no important tectonic deformations have subsequently affected these rocks. Such conditions have enabled the secondary albites and primary plagioclases to preserve their twins in an intact state. Besides, such conditions allow to eliminate the influence of the dynamic factor onto the character of the twins.

CARBONIFEROUS VOLCANIC ROCKS OF WAŁBRZYCH (SUDETES)

In the Wałbrzych Coal Basin (Intra-Sudetic Trough), the subvolcanic intrusions and lava flows of the so-called felsitic porphyries occur in the Culm conglomerates and in the Upper Carboniferous sandstones (Hoehne 1961; Grocholski 1965; Nowakowski & Teisseyre 1971). The largest intrusion is of the Chełmiec Laccolith[4], which together with its apophyses occupies an area of several square kilometers, and its relative elevation is about 280 m (7 in Fig. 1). Two extrusive bodies of similar volcanic rocks occur near that laccolith, namely between Czarny Bór and Stary Lesieniec (6 in Fig. 1), and another one south of Wałbrzych (Barbarka Hill, 8 in Fig. 1).

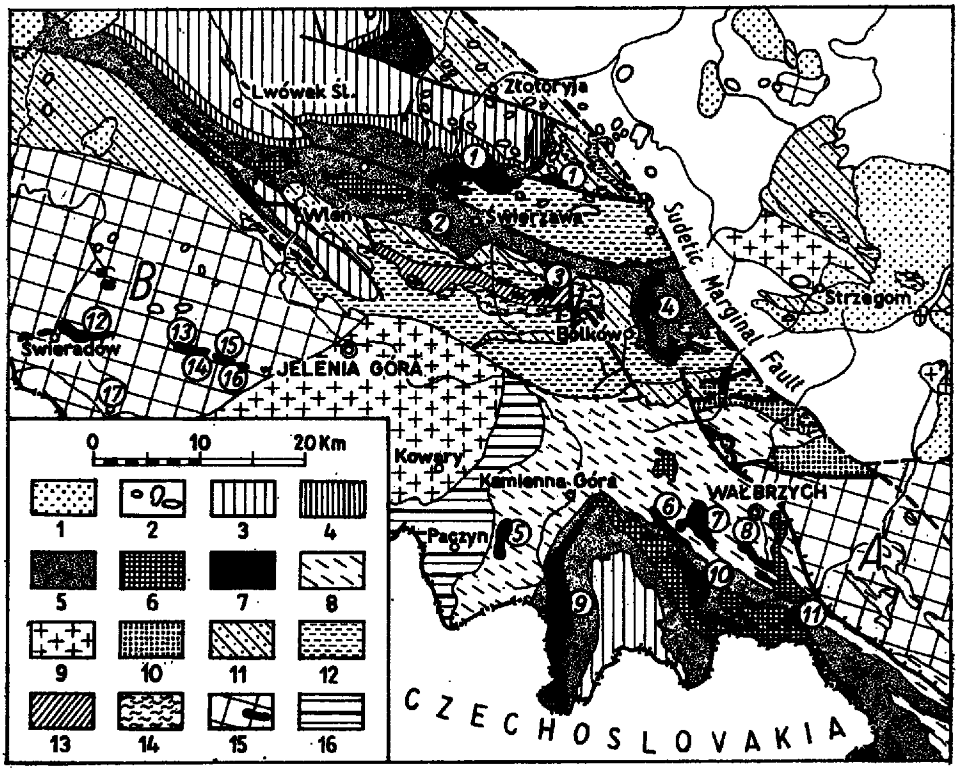

Fig. 1. Geological map of the Sudetes Mts, between Lwówek Śl. and Wałbrzych (*after* Teisseyre 1962; modified), showing the distribution of albitized igneous rocks (marked black)

1 — Tertiary deposits, *2* — Tertiary basaltoids, *3* — Triassic and Cretaceous deposits, *4* — Upper Permian deposits, *5* — Rotliegendes detrital deposits, *6* Rotliegendes trachybasalts, latites rhyolites, rhyolitic tuffs and ignimbrites, *7* — occurrences of Upper Carboniferous and Rotliegendes volcanic rocks containing albitized plagioclases (circled numbers *1—11* indicate volcanic bodies discussed in the text), *8* — Lower- and Upper Carboniferous detrital deposits, *9* — Variscan granitoids, *10* — Upper Devonian deposits, *11* — Silurian and Ordovician deposits, *12* — Higher Cambrian greenstone formation, *13* — Lower Cambrian limestones, *14* — Ryphean formations, *15: A* — Owl Mts (Góry Sowie) Archaic gneisses, *B* — Pre-Cambrian(?) gneisses, crystalline schists and leucogranites (black, marked by circled numbers *12—16*) of the Izera Mts, *16* — metamorphic cover of the Karkonosze granite (including the metavolcanites of the Leszczyniec Formation); circled number *17* — denotes the locality Garby Izerskie

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[4] "*Hochwald-Porphyr*" of German geologists.

The above igneous bodies yield aphyric or porphyritic type volcanic rocks of grey to greenish-grey and whitish color. Fine phenocrysts are represent by albite An_0, less frequently biotite, the latter being frequently largely replaced by chlorite or light mica with opacite rims of iron oxides and leucoxene. The main rock mass is composed of completely recrystallized volcanic glass of microcrystalline texture. It consists of grains of potassium feldspars ($2V_\alpha$ = 31—41°), quartz and euhedral laths of albite. The plagioclase there belongs to secondary albite which in some cases shows Pericline twins with preserved relicts of acid plagioclase. Exact composition of those relicts and the angles σ_{PCP} of the secondary albites are given in Table 2, Nos. 1, 2.

Table 2

Composition of primary plagioclase relics and σ-angles of Pericline (and Acline-A) twinned secondary albites ~An_0 occurring in Upper Carboniferous volcanic rocks from the vicinity of Wałbrzych, Inner Sudetic Trough

No.	Primary rocks	Relics of primary plagioclases		Secondary albites		
		composition mol. % An*	total number of examined grains	σ^o-PCP**	composition of primary plagioclase based on σ-PCP of secondary albite mol. % An	total number of examined grains
	Dellenites and rhyodacites:					
1	Chełmiec massif /Fig. 1 p. 7/	[30-37-39-30] ; [34-36-0] ; [35-18] ; [38-48] ; [42-12] ; 22; 30; 39;	8	0, 3	42, 34	38
	Rhyodacites:					
2	Czarny Bór - Stary Lesieniec belt /Fig. 1 p. 6/	38; 2 x 39; 40; 4 x 41; 42; 2 x 44; 46; 47; 50; 52;	15	0, 2 - 3	42, 34 - 32	56
3	Barbarka Hill /Fig. 1 p. 8/	not found	-	4.5, 5, 6.5	27, 26, 23	34
4	Massif at Stara Białka /Fig. 1 p. 5/	[31-21] ;	1	- 4.5	27	1
5	Żeleźniak Hill /Fig. 1 p. 3/	[42-30] ; [40-28] ;	8	0	42?	15

* The numerals in parantheses refer to the zoned plagioclase phenocrysts: the first numeral gives composition of the core and the subsequent ones composition of rims. The numerals with multiplication sign (*e.g.* 2X) denote the number of plagioclase relics of the same composition.
** The most frequent σ-values underlined.

Volcanic rocks, with relicts of primary plagioclases enclosed in albite phenocrysts An_0 (Pl. 1, Figs 1—2) accompanied by unaltered plagioclase plates, have been encountered at two sites, namely the lava flows at Czarny Bór and the middle part of the Chełmiec massif (*6, 7* in Fig. 1). The plagioclases are frequently Acline-A-twinned or Pericline-twinned with the composition plane parallel to (001). The composition of the relicts varies within the oligoclase-andesine range, and in the Chełmiec massif the plagioclase frequently show zonal structure (Table 2, No. 1), whereas at Czarny Bór they are homogenous (Table 2, No. 2). The albitized rhyodacites of the lava flow from the Barbarka Hill (*8* in Fig. 1) contain only albite An_0 phenocrysts without relicts of primary plagioclases. The albite phenocrysts frequently are Pericline-twinned. The σ_{PCP} angle of 4.5—6.5° indicates that originally they were acid plagioclases (Table 2, No. 3).

Before albitization, the Carboniferous rocks belonged to dellenites and rhyodacites (Nowakowski 1967; Nowakowski & Teisseyre 1971). Most of them were improperly classed as alkaline rhyolites by Plewa (1968).

The porphyries of the Stara Białka massif (*5* in Fig. 1), which form a plug in the Culm conglomerates (Berg 1941), belong most probably to the same group of volcanic rocks. In all exposures these rocks are the same type of almost completely albitized rhyodacite, with phenocrysts of albite An_0, strongly chloritized biotite, and sometimes with quartz. In the southern part of the massif, the albite phenocrysts show polysynthetic Pericline twins of σ_{PCP} angle = 4.5°. Relicts of primary oligoclase have been found in one albite An_0 phenocryst, only in a porphyry exposed close to the northern margin of the porphyritic massif (Table 2, No. 4). No Pericline twins have been found in the relicts.

A stock or a volcanic pipe of similar porphyritic rhydacite pierces the Early Paleozoic slates near Wojcieszów (Żeleźniak Hill, *3* in Fig. 1). The albitized rhyodacites there pass into texturally identical porphyries with phenocrysts of well preserved andesine, biotite, and quartz (Table 2, No. 5). The zoned plagioclases usually show delicate Acline-A or possibly Pericline lamellae with the composition plane parallel to (001).

All the discussed volcanic rocks are characterized by perfectly preserved porphyritic texture and do not show any essential dynamic deformation. Their potasium feldspars are strikingly resistant to albitization.

ROTLIEGENDES VOLCANIC ROCKS OF THE SUDETES AND WESTERN POMERANIA

In the Polish part of the Sudetes, the volcanic formation of the Rotliegendes occurs over the area of the Intra-Sudetic Trough south of Wałbrzych and Kamienna Góra, and in the North Sudetic Trough — near Lwówek Śląski, Świerzawa and Bolków (Fig. 1). The continuation of this formation is found east of the Sudetic Marginal Fault within the Fore-Sudetic Monocline deeply buried between Wrocław and Zielona Góra (Wyżykowski 1963; Nowakowski 1967). In recent years the volcanic rocks of the Rotliegendes were also encountered by boreholes in the Peri-Baltic part of Western Pomerania (Ryka 1968).

The volcanic rocks in the Intra-Sudetic Trough are up to about 750 m thick. The series consists of thick extrusive bodies of trachybasalts, latites, trachytes, rhyolites, and tuffs, as well as rhyolitic ignimbrites (Nowakowski 1967, 1968). The eruptive complex of the North Sudetic Trough is much less diversified, and it consists of trachybasalts, rhyolites, and rhyolitic tuffs (S. Kozłowski & Parachoniak 1967; Nowakowski 1967).

The trachybasalts are grey or black aphyric and porphyritic rocks. Basic plagioclases (andesine, labradorite, bytownite) are the dominant components of those rocks. Potassium feldspars ($2V_a \perp 010$ = 45—50°) occur in smaller quantities, and they form rims on plagioclase laths and separate grains associated with interstitial quartz. The most common mafic mineral in trachybasalts is diopside augite, which, in some cases, occurs with pigeonite. Olivine is less frequent and is usually replaced by serpentine or iddingsite. The relict olivine is of chrysolite Fa_{28} composition. Some trachybasalts of the Intra Sudetic Trough and all of the North Sudetic Trough contain orthopyroxene (bronzite, hypersthene Fs_{20-34}), or talc pseudomorphs after that mineral.

In many parts of the trachybasalt flows, the plagioclases are albitized to a various degree. Aside from trachybasalts with unaltered primary plagioclases, one may find trachybasalts rich in secondary albite, frequently with numerous relicts of primary plagioclases (Table 3, No. 1). In early stages of albitization of the plagioclases, irregular spots of albite develop which exhibit the same orientation within each lamella, while in different lamellae they are related to each other by the same twinning laws as the relict parts of the primary plagioclase (Pl. 1, Figs 3—4).

Table 3

Composition of primary plagioclase relics and σ-angles of Pericline (and Acline-A) twinned secondary albites $\sim An_0$ occurring in Lower Permian volcanic rocks in the Sudetes Mts.

No.	Primary rocks	Relics of primary plagioclases		Secondary albites		
		composition mol. % An*	total number of examined grains	σ^{o}-PCP**	composition of primary plagioclase based on σ-PCP of secondary albite mol. % An	total number of examined grains
	Trachybasalts:					
1	Inner- and North Sudetic Troughs /Fig. 1/	45 - 50; 60 - 70;	46	0, -3	?, 57	110
2	Fore-Sudetic Monocline	52; 58;	2	0	?	87
3	Western Pomerania	46; 47; 52; 55; 60; 61; 65; 68;	8	0, 3	?, 34	13
	Anorthoclase latites:					
4	Inner Sudetic Trough /Fig. 1 p. 10/	[46/core/, 26/rim/]; 33; 8 x 35; 11 x 38;	21	0	?	91
	Cuselite:					
5	Nahe, Remigiusberg	35;	2	0	?	6
	Trachytes:					
6	Inner Sudetic Trough /Fig. 1 p. 9/	22; 26/$2V_{\alpha}$ = 74.3°/;	2	0	?	23
	Rhyodacites and dacites:					
7	Fore-Sudetic Monocline	not found	-	4 - 5.5	29 - 24	27
	Rhyolites:					
8	Świerzawa /Fig. 1 p. 1/	23/σ = 4.6°/; 25; 32; 35; 38;	5	2, 3.5, 4.5	34, 30, 26	45
9	Bolków /Fig. 1 p. 4/	not found	-	3.5, 4	30, 28	19
10	Łomnica /Fig. 1 p. 11/	18; 20; 22; 24; 30;	6	0	?	7

* The numerals with multiplication sign (*e.g.* 8X) denote the number of plagioclase relics of the same composition.
** The most frequent σ-values underlined.

In cross-sections, the lava flows reveal a definite differentiation in texture and in degree of albitization of the plagioclase, as illustrated by trachybasalts from Lubiechowa near Świerzawa (Fig. 2). In its lower part, the trachybasalt flow is almost unaltered, black, without vesicles, and with plagioclase of andesine and labradorite composition. Upwards, the number of vesicles increases distinctly, the plagioclases are progressively replaced by albite, and the rock is rusty-brown in color. The relicts of primary plagioclases, preserved in albite pseudomorphs, reveal the same composition as the unaltered plagioclases (andesine, labradorite). The

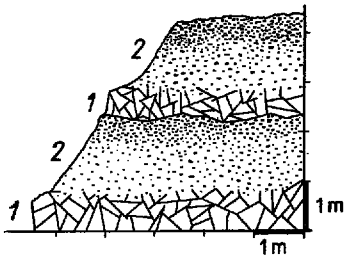

Fig. 2. Cross-section of the two trachybasalt flows exposed at the Lubiechowa quarry near Świerzawa, Kaczawa Mts

1 — almost vesicle-free trachybasalt containing dominant plagioclases of An53-65 composition, *2* — trachybasalt containing toward the top more and more albitized plagioclases and vesicles filled by chlorite, calcite and chalcedony

albitization processes in the trachybasalts of the oldest lava flows are sometimes related to large irregular fissures. Frequent polysynthetic Acline-A twins are a characteristic feature of the primary plagioclases and of the albites formed at their expence in trachybasalts, whereas the Pericline twins are rare (Table 3, No. 1).

The albitization of the plagioclases was associated with chloritization of the augites and serpentinization of the olivines and orthopyroxenes. There is also evidence of local riebeckitization of postaugite hornblende and olivine, as well as spontaneous crystallization of riebeckite on epidote grains (Nowakowski 1957; K. Smulikowski 1957).

Albitized latites with phenocrysts of anorthoclase, albite, and sometimes andesine (Nowakowski 1968), are similar to trachybasalts. Thick latite flows occur south of Wałbrzych between Unisław Śląski and Mieroszów (*10* in Fig. 1). Latites are characterized by equal quantities of well preserved potassium feldspars ($2V_a \perp 010 = 40$—$53°$) and secondary albites An_0, which have developed at the expense of the primary andesine. In some cases they occur as relicts preserved in albite, and sporadically as separate unaltered laths (Table 3, No. 4). The lack of Pericline twinning is a characteristic feature of albites and relict andesines, whereas Acline-A twinning is common. Mafic minerals (?pyroxenes) have undergone complete hematitization as well as chloritization, and in places also carbonatization.

The Permian cuselites from Cusel (Saar-Nahe area, West Germany), long regarded to be strongly altered by "autohydrometamorphic" type processes (Bambauer 1956), show a striking similarity to the albitized trachybasalts and some varieties of the Sudetic latites. Samples of these rocks from the Remigiusberg Hill, coming from the collection of Dr. F. Krantz, Bonn abound in laths and tabular crystals of An_0 albite, which sometimes is accompanied by phenocrysts of relict andesine (Table 3, No. 5). The examined feldspars lack Pericline twinning but they show Acline-A twins. In the cuselites, as in the Permian volcanic rocks of the Sudetes, a distinct resistance of potassium feldspars ($2V_a \perp 010 = 44$—$46°$) to albitization is striking. These minerals accompany the interstitial quartz and form rims on some albite laths. Of the mafic minerals, only biotite remained in its primary state of preservation in the cuselites.

The trachyte flows, up to about 200 m thick, form a narrow mountain belt stretching meridionally from Kamienna Góra as far as Czechoslovakian frontier (*9* in Fig. 1). The mineral composition of those aphyric rocks is very monotonous, consisting of a mainly microcrystalline groundmass of usually xenomorphic grains of potassium feldspar and interstitial quartz with an admixture of rusty iron oxides. Undoubtedly, it is a product of recrystallization of abundant glass in which scarce phenocrysts of sanidine and orthoclase $Ab_{35—40}$ ($2V_a \perp 010 = 10$—$52°$) are enclosed together with albite An_0, as well as mafic minerals completely replaced by rusty oxides. Albite phenocrysts sometimes contain spots of relict oligoclase (Pustelnia Hill near Lubawka) indicative of the secondary nature of these feldspars (Table 3, No. 6). Only twin-bands of Acline-A type have been found in albites instead of Pericline twins.

The rhyolite extrusive bodies occur both in the Intra-Sudetic and in the North-Sudetic Troughs. The largest one, about 10 km long, occurs north of Świerzawa (*1* in Fig. 1); its thickness is estimated at 80—120 meters. Other rhyolite extrusive bodies in the vicinity of Bolków and Łomnica are considerably smaller (*4* and *11* in Fig. 1).

All three extrusive bodies are composed of very similar porphyritic rhyolites with abundant phenocrysts of sanidine or orthoclase ($2V_\alpha \perp 010 = 10$—$45°$), albite An_0, quartz, and biotite. The profuse groundmass is formed by completely recrystallized glass of microcrystalline texture. It consists of fine xenomorphic grains of potassium feldspar and quartz and small laths of albite An_0 and biotite plates almost completely replaced by hematite. Albite is here undoubtedly secondary, as sometimes it contains relicts of oligoclase and andesine, *e.g.* in rhyolites near Świerzawa (*1* in Fig. 1; localities Sokołowiec and Różana) and in rhyolites at Łomnica (*11* in Fig. 1). An unaltered lath of oligoclase An_{26} associated with phenocrysts of albite An_0 was encountered in the last-mentioned rhyolite, whereas no relict plagioclases were found in the albites of the Bolków rhyolites (*4* in Fig. 1).

Pericline twins are frequent in the albites and in relict plagioclases of the rhyolites from Świerzawa and Bolków (Table 3, Nos 8—10; Fig. 6*c*—*e*; Pl. 3, Fig. 1), whereas in the albites of the rhyolites from Łomnica, only multiple Acline-A twins were noted. The potassium feldspars of these rocks are well preserved and only in some places have they undergone slight albitization (in the Bolków rhyolites, some sanidine phenocrysts are replaced by chessboard albite).

The albitization processes were also very active in the Rotliegendes volcanic rocks of the Fore-Sudetic Monocline. Samples from the boreholes of Czeklin, Jany, Kąkolewo, Pomorsko, Rawicz, Starosiedle, and Trzebule usually represent strongly metasomatized trachybasalts, dacites, rhyodacites, and rhyolites. The albites commonly lack relicts of primary plagioclases in the dacites and rhyodacites, whereas in trachybasalts the albites formed at the expense of basic plagioclases show Acline-A twins (Table 3, Nos 2, 7).

Albite porphyries from the Trzebule borehole (depth 2655.1 m) are among the most interesting volcanic rocks of the Fore-Sudetic Monocline. Previously, they were improperly classed as alkaline rhyolites. Actually, they were typical dacites (Table 3, No. 7) which had attained a rhyolitic character from thorough albitization of primary plagioclases (oligoclase).

Phenocrysts of potassium feldspar in the rhyolites of the Fore-Sudetic Monocline are frequently replaced by chessboard albite (Pomorsko borehole, depth 2873.6—2879.0 m) which, however, always contain relicts of primary feldspar.

In the Peri-Baltic part of Western Pomerania, the Rotliegendes volcanic rocks have been encountered at Kamień Pomorski and at Dźwirzyn (depths 2721.8 m and 2530.5 m respectively; *cf.* Ryka 1968). The albitization of basic plagioclases (mainly labradorite) is here well pronounced, which proves a regional range for that process. Ryka (1968) referred to those rocks as secondary rhyolites, but according to the present author's investigations, their primary composition was probably trachybasaltic.

In samples kindly supplied by Dr. W. Ryka, many relicts of basic plagioclases are preserved in phenocrysts of pure albite of perfectly developed twins (Table 3, No. 3). Typical Pericline twins in those feldspars have been found only sporadically, whereas the Acline-A ones are fairly common.

CAMBRIAN VOLCANIC ROCKS AND CALEDONIAN DYKES OF THE KHASAGTU KHAYRKHAN ULA MTS (WESTERN MONGOLIA)

Evidences of a very strong sodium metasomatism are known in the lava flows and numerous dykes in the Khasagtu Khayrkhan Ula Mts of Western Mongolia (Nowakowski 1969). The eruptive rocks represent there Early and Middle Cambrian volcanism, whereas the dykes are probably of Caledonian age (S. Kozłowski 1969).

According to S. Kozłowski (1969), the Cambrian volcanic series of the Khasagtu Khayrkhan Ula Mts represents a subsequent volcanism which succeeded the Baikalian and Salairian orogenic movements mainly in the Dzabkhan Depression which is a vast foreland graben (Fig. 3). The lava flows of those rocks are interbedded with terrigenous sediments, and also, in the upper part of the section, with marine strata (Middle Cambrian limestones with Archaeocyathidae). The Cambrian eruptive complex consists of basalts up to 200 m thick, and even thicker rhyodacites, dacites, and subordinately trachytes. These rocks, and their acid varieties in particular, contain plagioclases which are almost completely replaced by albite, while the pyroxenes and biotite are altered to chlorite. The perfect state of preservation of the primary porphyritic, fluidal and amygdaloidal textures is a feature common to all these altered volcanic rocks. The acid volcanic rocks which primarily abounded in glass show eutaxitic texture, expressed by a system of thin laminae of recrystallized glass. The interlaminous spaces are frequently filled in with fine-grain albite or quartz of hydrothermal origin. Hydrothermal albite is also concentrated in nests and amygdales, and is accompanied by calcite, ferruginous epidote, and quartz (Nowakowski 1969).

The basalts are characterized by monotonous composition and porphyritic, intergranular, and fluidal textures. Their unaltered varieties abound in laths and tabular crystals of labradorite An_{55-72}, andesine An_{42}, and in some cases of anorthite An_{94}. Diopside augite is the main dark mineral, and subordinate olivine has been completely replaced by serpentine pseudomorphs. The metasomatized counterparts of the basalts contain numerous laths of albite An_0 with epidote inclusions and occasionally relicts of basic plagioclases (Table 4, No. 1). Both the relict plagioclases and the albite pseudomorphs after these feldspars, are twinned according to the Acline-A law, and are thus similar to the previously described primary plagioclases and secondary albites of the Permian trachybasalts (Table 3, Nos 1—3).

The rhyodacites, dacites, and trachytes are usually developed as porphyritic rocks. The most common phenocrysts are: tabular albite An_0, sometimes with inclusions of yellowish epidote (Pl. 2, Figs 1—2), quartz, and biotite, the latter usually strongly or completely chloritized. Phenocrysts of potassium feldspar ($2V_\alpha \perp 010 =$ $= 53$—$67°$) which is partly replaced by chessboard albite are seldom found in the rhyodacites. The detection of relict plagioclases in these rocks was more difficult than that in the basalts. Phenocrysts of primary plagioclase (andesine) have been found only in rhyodacites in two exposures situated north of the road from Chovd to Ulhan Bator (Nos *1* and *2* in Fig. 3). Initial stages of albitization of those feldspars are expressed by irregular albite veinlets. The plagioclases in rhyodacites from exposure No. *1* show Pericline, and those from exposure No. *2* — Acline-A twinning. The secondary albites An_0 of the examined rhyodacites and dacites show frequent Pericline and occasionally Acline-A twins. The σ_{PCP} angles in those feldspars are very close to the respective angle in the relict andesine (Table 4, No. 2).

Numerous vein intrusions of probable Caledonian age occur over the whole area of the Khasagtu Khayrkhan Ula Mts (S. Kozłowski 1969). Those are mostly dykes of diabase, andesite, trachyandesite, and lamprophyre, which could not be shown in Fig. 3. The dykes intersect the volcanites and Cambrian sandstones and limestones and they also are known to occur in the massifs of the Salairian granitoids.

Basic plagioclases of the Caledonian vein rocks are frequently albitized, and their pyroxenes have undergone strong uralitization, chloritization, and carbonatization. Relicts of basic plagioclases and the secondary albites developed at the expense of those feldspars are mostly Acline-A twinned (Table 4, Nos 3—4). The

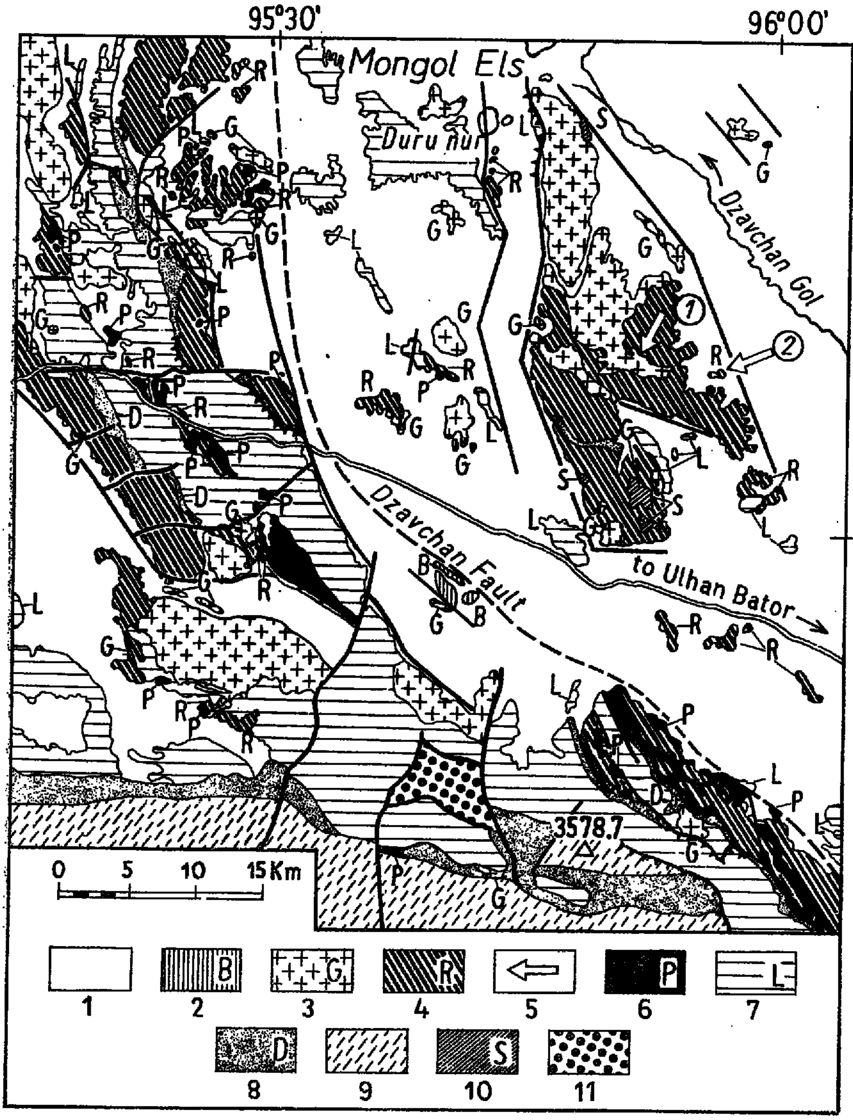

Fig. 3. Geological map of the northern part of the Khasagtu Khayrkhan Ula Mts in Western Mongolia (based on the map by Kozłowski 1969, and on petrological studies by the writer — Nowakowski 1969)

1 — Quaternary and Tertiary deposits, *2* — Quaternary basalts, *3* — Salairian granitoids, *4* — Lower- and Middle Cambrian albitized rhyodacites, dacites and trachytes, *5* — outcrops (numbered *1*, *2*) of rhyodacites containing primary plagioclases associated with secondary albites, *6* — Lower- and Middle Cambrian strongly albitized basalts, *7* — Middle Cambrian limestones and dolomites, *8* — Lower Cambrian detrital deposits, *9* — Sinian metabasalts, albitized dacites, rhyodacites and rhyolites, *10* — Sinian gabbros and diabases, *11* — serpentinized dunites

Table 4

Composition of primary plagioclase relics and σ-angles of Pericline (and Acline-A) twinned secondary albites $\sim An_0$ occurring in albitized volcanic rocks of the Khasagtu Khayrkhan Ula Mts, Western Mongolia

No.	Primary rocks	Relics of primary plagioclases		Secondary albites		
		composition mol. % An	total number of examined grains	$\sigma°$-PCP*	composition of primary plagioclase based on σ-PCP of secondary albite mol. % An	total number of examined grains
	Cambrian volcanic rocks:					
1	Basalts /Fig. 3/	42 - 65; 72; 94;	174	<u>0</u>	?	88
2	Rhyodacites and dacites /Fig. 3/	23; 30/σ = 4.4°/; 33, 34/$2V_\alpha$ = 83.5°/	4	0, 3.5 - 4.5;	? 30 - 27	93
	Caledonian dyke rocks:					
3	Diabases	50 - 60; 79 - 85;	43	<u>0</u>	?	49
4	Andesites	46; 53;	2	-	-	17
5	Trachyandesite from the Ulin-daba Pass	not found	-	<u>0</u>	?	7
6	Trachyandesite of the Boro-nuru massif	not found	-	<u>4</u>, 5	29, 25	11

* The most frequent σ-values underlined.

same type of twinning occurs in the albite pseudomorphs after plagioclases from a vein of altered trachyandesite (Table 4, No. 5). A similar trachyandesite from another vein contains a secondary albite An_0 with inclusions of epidote. It is predominantly Pericline-twinned, sometimes in a combination with the Ala-A law (Table 4, No. 6).

VARISCAN GRANITOIDS OF THE STRZEGOM-SOBÓTKA MASSIF (SUDETIC FORELAND)

Evidences of intense albitization of plagioclases are clearly expressed also in some granitoids of the Strzegom-Sobótka Massif (Sudetic Foreland). Granodiorites grading into granites, with biotite as the main mafic mineral, are dominate in that massif (Borkowska 1959; Majerowicz 1963, 1972). These rocks when unaltered are grey, whereas their albitized counterparts show a white color.

The largest quantities of white albitized granite occur in the vicinity of Sobótka. Transitions to grey, unaltered granodiorites may be observed in the large quarries at Strzeblów and Chwałków (*2—4* in Fig. 4). In the oldest quarry at Strzeblów (*1* in Fig. 4) only the so-called *"white kaolinized granite"* is exposed. Previously, it was regarded as a peculiar product of differentiation of granitic intrusion (Smulikowski, Teisseyre & Oberc 1957). Majerowicz (1963, 1972), on the other hand, is of the opinion that all the white granites in the vicinity of Sobótka are due to autometamorphosis of previously cataclazed grey granitoids, and that the process resulted in the disappearance of biotite from these rocks, an enrichment in quartz, and local albitization.

The albitization of plagioclases is expressed also in other parts of the Strzegom-Sobótka Massif but to a lesser degree: there are only local zones of white granite occurring near aplite and pegmatite veins (Żółkiewka, Strzegom, Kostrza).

Such rocks are sometimes enriched in quartz, prehnite, epidote, chlorite, calcite, and zeolites.

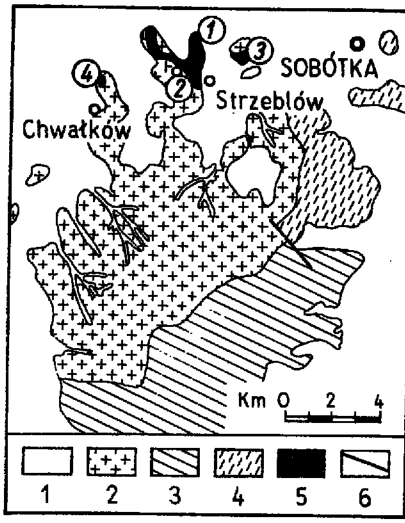

Fig. 4. Geological map of Variscan granitoids in the vicinity of Sobótka (*after* Majerowicz 1963)
1 — Quaternary and Tertiary deposits, *2* — unaltered biotite granodiorite with grey colouration, *3* — metagabbro, *4* — orthoamphibolites and serpentinites, *5* — albitized granodiorite, white in colour (circled numbers *1*—*4* indicate exposures), *6* — faults

Grey granodiorites and white granites are identical in texture and fabric, but differ in the plagioclase composition. Grey granodiorites from Strzeblów and Chwałków abound in plagioclases which are accompanied by microcline ($2V_\alpha = 74$—$86°$), quartz, and biotite. Usually the plagioclases are zoned. The andesine An_{38}—$_{33}$ cores are surrounded by oligoclase and albite rims of various *An*-content. Oligoclase and albite grains devoid of zoning occur subordinately. The most common compositions of the 40 examined plagioclase grains are presented in Table 5, No. 1.

The white granites, which rather sharply pass into grey granodiorites, contain only grains of albite $\sim An_0$ without relicts of primary plagioclase. Microcline is partly changed into chessboard albite, and biotite is completely replaced by chlorite.

Table 5

Examples of composition variability of primary plagioclases and of σ-angles of secondary albites $\sim An_0$ occurring in granodiorites of the Strzegom-Sobótka massif

No.	Locality	Primary plagioclases	Secondary albites	
		composition mol. % An*	$\sigma°$-PCP	composition of primary plagioclase based on σ-PCP of secondary albite
1	Strzeblów and Chwałków	[38-26-20-11-6-10] ; [37-30-19]**; [29-21-16] ; [28-25-22-20-17-13-10-0-10] ; [28-23-20-13-10-0] ; 15; 11; 10;	[0-4-11-13-18-20-25] ; [0-8.5-18] ; [13-19] ; [13.5-11] ;	[55/?/-38-26-23-17-15-9] ; [55/?/-30-17] ; [23-16] ; [22-26] ;
2	Żółkiewka	[21-9-0] ; 15; 14;	[6-10-30] ; [7-9] ;	[33-28-1] ; [32-30] ;

* An-contents and σ-angles of zoned feldspar grains are listed in parantheses. The first numeral refers to the core and the subsequent ones to the consecutive zones.
** The observed σ-*PCP* angles are 4.6°, 7° and 18.4°, respectively.

or light mica with associated iron and titanium oxides. Clinozoisite prisms and pyrite are also present. According to the author, the variation of the σ_{PCP} angles within the individual albite grains (Fig. 8), seems indicative of compositional zoning of original plagioclases in the range very close to that known from the zoned plagioclases of grey unaltered granodiorites (Table 5, No. 1).

Similar features are shown by the plagioclases of grey unaltered granodiorites and of white albitized granites from the quarry at Żółkiewka near Strzegom. In a large-size thin section embracing both grey and white portions of the rock, the texture and fabric are identical. The composition of the primary zoned plagioclases from the grey portion of granodiorite corresponds to oligoclase and albite. In the author's opinion, the original composition of the secondary albite An_0 from the white part of the granitoid, as shown by the σ_{PCP} angles, corresponds to acid andesine and albite (Table 5, No. 2).

MICROSCOPIC FEATURES OF THE ALBITES REPLACING THE PRIMARY PLAGIOCLASES

The albite phenocrysts of the examined volcanic rocks form fine platelets from about 4 up to 7 mm, in which the {010}-pinacoid is best developed. They are whitish or pinkish, sometimes semitransparent. The albite grains in granitoids are white and nontransparent, usually anhedral, and of maximum diameter about 10 mm. The albites of the Mongolian volcanic rocks contain inclusions of ferrian epidote (pistacite), and less frequently calcite. In general, the albites replacing primary *An*-rich plagioclases contain more epidote inclusions. Calcite inclusions are particularly common in the albites of the Sudetic trachybasalts, and they are almost lacking in the albites of rhyolites, trachytes, rhyodacites, and granitoids. All the examined albites contain particles of iron oxide, and some inclusions of sericite and chlorite.

Relicts of primary plagioclases in the form of irregular patches are the most important components of some albites in volcanic rocks (Figs 6*a*—*c;* and Pl. 1, Figs 1—2). In some cases, traces of pre-existing zoning are preserved in such feldspars (Pl. 1, Fig. 1). They were described earlier by Nowakowski & Teisseyre (1971).

The albites and primary plagioclases were studied by microscopic methods in thin sections and splinters (001), (010). The determinations of the composition, identification of twinning laws, and conoscopic measurement of optic axial-angle (with precision of $\pm$ 1°) were done with a universal stage. The refractive indices were established to an accuracy of $\pm$ 0.001 using the Berek microrefractometre mounted on the universal stage. The composition of feldspars was established on the basis of the diagrams and stereograms of Burri, Parker & Wenk (1967).

The σ_{PCP} angle in the albites in question should be measured on the (010) face. As the separation of the albites was in many cases impossible, this value was measured in thin sections of those feldspars oriented

$\perp$ [010]. As the maximal obliquity $\Phi = 4.4°$ in albites (Starkey 1967), the σ angle measured in such a way only slightly deviated from the σ values measured on the (010) face.

Measurement of the orientation of PCP in albites requires a determination of the sign of the σ angle, which in acid plagioclases is positive, and negative in the strongly basic ones (Fig. 10). By convention, the sign of the σ angle is positive when the trace of *PCP* is within the obtuse angle between the crystallographic axes $+a$ and $+c$, and is negative when that trace is within the acute angle between the axes $-a$ and $+c$. The position of these axes in the (010) section of an automorphic feldspar is marked by traces of cleavage of (001) and (100) face, which cut each other at an angle of about 116° (Fig. 10). If the identification of the (100) face is impossible, the sign of the σ angle may be determined only in relation to the vibration direction α', which in albite An_0 is between the crystallographic axes $+a$ and $+c$, forming an angle of 20—22° with the trace of cleavage (001) [this value in secondary albite An_0 of volcanic rocks may drop down to 12—16°; see Table 6]. It follows that if the trace of *PCP* in albite is roughly "parallel" to the vibration direction α' (Fig. 6*c*—*f*), the σ angle is positive; but if these directions are divergent (Fig. 6*g*), the σ angle is negative.

OPTICAL PROPERTIES AND (Al, Si)-ORDERING

The secondary albites of the volcanic rocks sometimes exhibit delicate streaky structure when observed under high magnification. This property, caused by an optical inhomogeneity, does not influence the precision of optical measurements. The extinction angles in sections $\perp$ [100] and the refractive indices both are indicative of the composition of pure *Na*-feldspar (Table 6). On the other hand, the extinction angle $\alpha \wedge$ (001) in albite section $\perp \gamma$ or in splinters (010) indicated a different composition. In pure albite, that angle should be 20° (Burri, Parker & Wenk 1967) whereas in the investigated albites it ranged from 12° to 22° (Table 6) — the value which in ordered plagioclase would correspond to an anorthite content of An_{16} to An_0.

In fact, the albites in question may contain but a small admixture of anorthite. This may be inferred from the chemical composition of a secondary albite phenocryst from an Upper Carboniferous rhyodacite which crops out at Czarny Bór (*6* in Fig. 1). The composition of this feldspar as determined by electron microprobe analysis by Doc. J. Serkies is (in mol. per cent): $Ab_{98.7} An_{0.8} Or_{0.5}$. Potassium reported as *Or* molecule is most probably a component of sericite. Very small anorthite $An_{0.03}$—$An_{1.36}$ contents in secondary albites of igneous rocks were found also by Callegari & De Pieri (1967) by means of electron microprobe analysis. These determinations show that the chemical composition of secondary albites in igneous rocks is very close to that of pure *Na*-feldspar.

The variation of optic axial angle in the albites studied is shown in the Slemmons' (1962) diagram (Fig. 5), which permits the rough determination of the ordering state of those feldspars. It is described by the "*intermediacy index*" (*I. I.*), which in disordered plagioclases is 0, but in fully ordered ones is 100. The diagram shows that in the albites the (*Al, Si*)-ordering state varies from an intermediate to fully ordered one (*I. I.* from 60 to 100 respectively). Besides, one may notice that, unlike the secondary albites of volcanic rocks, those of the investigated granitoids (Table 8) show the ordering state more stable and almost maximal.

Table 6

Optical properties of secondary albites $\sim An_0$ occurring in albitized volcanic rocks from the Sudetes, and from Khasagtu Khayrkhan Ula Mts (Western Mongolia)

No.	Rock name	Extinction angles		$2V_\alpha$ $\pm 1^\circ$	Refractive indices $\pm$ 0.001
		$\perp$ [100] $\alpha \wedge (010)$ (−)	$\perp \gamma$ $\alpha \wedge (001)$ (+)		
	Sudetes Mts:				
1	Permian rhyolites and trachytes	14 - 19° /230/	12 - 20° /276/	89 - 96° /127/	$n\alpha$ D: 1.528 - 1.531 /61/ $n\beta$ D: 1.531 - 1.533 /28/ $n\gamma$ D: 1.536 - 1.538 /61/
2	Upper Carboniferous rhyodacites	16 - 19° /140/	18 - 22° /91/	88 - 98° /38/	
3	Permian latites	15 - 18° /138/	12 - 19° /147/	80 - 92° /81/	
4	Permian trachybasalts	15 - 17° /230/	12 - 19° /276/	78 - 92° /127/	
	Khasagtu Khayrkhan Ula Mts:				
5	Cambrian basalts, rhyodacites and dacites	15 - 17° /288/	19 - 21° /196/	83 - 105° /175/	

Quantities of examined albite grains are given in parantheses.

One may conclude that the intermediate states of ordering are a characteristic feature of secondary albites of volcanic rocks. The *2V* angles known so far in albi-

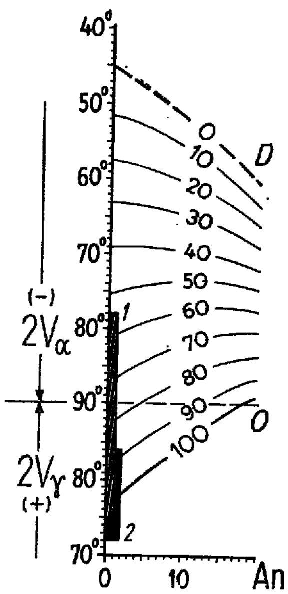

Fig. 5

Optic axial angle and intermediacy index (*I. I.*) of albite pseudomorphs after primary plagioclases from the Sudetic and Khasagtu Khayrkhan Ula volcanic (*1*) and granitoidic (*2*) rocks (based on diagram by Slemmons 1962)

D — disordered plagioclases (*I.I.* = 0), O — ordered plagioclases (*I.I.* = 100)

tes of volcanic rocks are given in Table 7. Most of those feldspars are pseudomorphs after primary plagioclases of various composition. The anorthite contents shown in the table were taken from literature and in many cases most probably are overestimated. Their composition was determined by the classical method of

Table 7

Optic axial angles of secondary albites and the composition of primary plagioclases from various volcanic rocks

No.	Occurrences	Albites		Primary plagioclase	References
		mol. % An	$2V_\alpha$		
1	Permian volcanites, Sudetes	0	78 - 92°	oligoclase-labradorite	Nowakowski, 1968
2	Jurassic diabases, Crimea	7 - 12	79 - 88°	andesine-anorthite	Lebedinskij, 1962
3	Pre-Albian/?/ keratophyres, Virgin Islands	0	80 - 90°	albite*	Donnelly, 1963
4	Quaternary and Tertiary andesite-dacite tuffs and lavas, Kamchatka	2 - 7	82 - 86°	andesine-bytownite	Rusinov, 1965
5	Cambrian spilites and keratophyres, West Sayan	2 - 4	82 - 110°	albite*	Velinskij, 1968
6	Cambrian basalts, rhyodacites and dacites, Western Mongolia	0	83 - 105°	oligoklase-labradorite	Nowakowski, 1969
7	Granite porphyries, Schwarzwald; quartz porphyries, Vosges; tuffite-sandstones, Taveyannaz /Alps/	0 - 10	85 - 86°	?	Glauser, 1959
8	Permian quartz porphyries, Bozen /Alps/	0 - 7	85 - 100°	oligoclase-andesine	Karl, 1954
9	Permian porphyrites, Weyhausen /West Germany/	10	90 - 100°	?	Drong, 1958

* Primary albites according to the cited authors.

measurement of the optical orientation of twins by means of the universal stage, but this method is known to be inaccurate.

The albites from keratophyres and spilites (reported in Table 7, Nos 3 and 5) have been classed by Donnelly (1963) and Velinskij (1968) as primary feldspars which, however, is hardly convincing. Donnelly (1963) found in a keratophyre, along with albite phenocrysts, plagioclase An_{19-22} which was partly replaced by albite. Velinskij (1968) based his conclusion on the values of the $2V$ and Θ angles $(\bar{1}32)$ and $(\bar{1}31)$ which indicate a high-temperature origin for these feldspars and, according to that author, suggest the primary origin of albite in spilites. This conclusion, however, may be erroneous, as the evidence of high-temperature origin is the intermediate state of ordering which, as demonstrated previously, is characteristic of the metasomatic albite of volcanic rocks (Fig. 5). A similar ordering state was found also by Baskin (1965) in low-temperature albite of authigenic origin. It is highly probable that the albite studied by Glauser (1959, cf. Table 7, No. 7) are secondary as well, as is suggested by their intermediate structural state and by the advanced alteration of the rocks in which they occur (chloritization of biotite, sericite in feldspars, carbonates).

The intermediate states of ordering of secondary albites of volcanic rocks are caused most probably by the fact that (*Al*, *Si*)-ordering of primary plagioclase may be inherited by secondary albite. Such a conclusion is supported by the fact that the primary plagioclases preserved in the albitized Sudetic and Mongolian volcanic rocks are characterized by intermediate state of ordering as it is the case with the secondary albites (Nowakowski 1967, 1968, 1969). Additional evidence may be also looked for in experimental studies which have shown that exchange of alkaline ions in feldspar under unhydrous environment does not result in a change of the ordering state of *Al* and *Si* atoms (Laves 1951; Wyart & Sabatier 1956a, b, 1961; Goldsmith & Laves 1961; Duffin 1964; Orville 1962, 1963; Manecki 1970).

Table 8

Optical properties of secondary albites ~An_0 occurring in albitized granitoids from the Sudetes, and from the Khasagtu Khayrkhan Ula Mts (Western Mongolia)

No.	Rock name	Extinction angles		$2V_\gamma$ ± 1°	Refractive indices ± 0.001
		⊥ [100] α ∧ (010) (−)	⊥ γ α ∧ (001) (+)		
	Sudetes Mts:				
1	Variscan granodiorites, Strzeblów, Chwałków, Żółkiewka	15 - 16° /66/	20 - 24° /47/	78 - 80° /32/	$n\alpha_D$: 1.528 - 1.531 /53/ $n\beta_D$: 1.532 - 1.534 /14/ $n\gamma_D$: 1.536 - 1.538 /53/
2	Variscan granodiorites, Česka Čermna massif	16 - 18° /19/	21 - 23° /33/	79 - 84° /26/	
3	Variscan vein granodiorite, Strzelin	16 - 17° /6/	20 - 23° /14/	72 - 73° /11/	
4	Precambrian leucogranites, Izera Mts	15 - 16° /49/	20 - 24° /53/	76 - 81° /48/	
5	Variscan aplogranite, Garby Izerskie	14 - 15° /10/	17 - 21° /12/	82 - 83° /11/	
	Khasagtu Khayrkhan Ula Mts:				
6	Salairian granodiorites and adamellites, Boro-nuru massif	14 - 16° /43/	20 - 22° /51/	78 - 82° /30/	

Quantities of examined albite grains are given in parantheses.

Secondary albites of the previously described white albitized granites (Strzeblów, Chwałków, Żółkiewka) also show the optical properties of pure *Na*-feldspar (Table 8, No. 1). They differ from the albites of volcanic rocks by an almost constant extinction angle $\alpha \wedge (001)$ in sections $\perp \gamma$ (20—22°), and always are optically positive. The $2V\gamma$ axial angle is constant as well, indicating a very low structural state, represented by an intermediacy index *I. I.* = about 100 (Table 8, No. 1; and Fig. 5).

TWINNING OF ALBITES

Albite, Pericline and Acline-A twins are most frequent in the secondary albites of volcanic rocks. Combinations with the Carlsbad, Ala-A, and sometimes with the Ala-B and Baveno twins are common. Aside from simple twins according to Baveno Law, the so called *"Banater Verwachsungen"* of Burri (1963) is found.

Studies with the universal stage have proved that secondary albite twinned according to the above laws inherits twin axes, composition planes (010), (001), and *PCP* from primary plagioclases. The inheritance by albite of twinning structure from primary plagioclase was pointed out by the present author in earlier papers (Nowakowski 1957, 1967, 1968, 1969), and is illustrated here by examples shown in

Fig. 6a—c. Figure 6a shows Carlsbad twinning common in andesine and albite partly replacing andesine. The mutual orientation of these twins is characterized by the

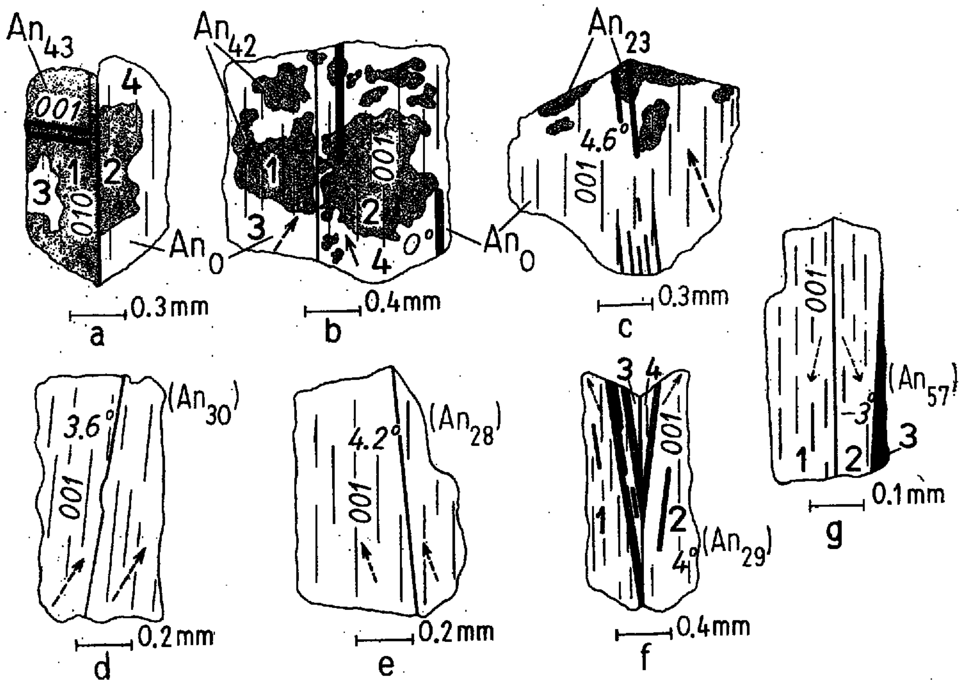

Fig. 6. Twinnings inherited by secondary albites An_0 (white parts) after primary plagioclases (stippled) in albitized volcanic rocks of the Sudetes Mts and Khasagtu Khaynkhan Ula Mts; black bands represent Pericline (or Acline-A?) lamellae

a — parts of relic andesine (1—2) and of secondary albite (3—4) twinned according to Carlsbad law; orientation ⊥ [100]; Upper Carboniferous rhyodacite from Czarny Bór, Inner-Sudetic Trough,

b — parts of relic andesine (*1—2*) and of secondary albite (*3—4*) twinned according to Ala-A and Pericline ($\sigma = 0°$) or Acline-A? laws; host rock as previously,

c — parts of oligoclase and of secondary albite twinned according to Pericline law; Permian rhyolite from Sokołowiec, Kaczawa Mts,

d, e — single Pericline twins in secondary albites; Permian rhyolites from Bolków (*d*) and Sokołowiec (*e*) in the Kaczawa Mts,

f — Ala-A (*1—2*), Manebach (*3—4*) and Pericline twins of secondary albite; Cambrian rhyodacite of the Khasagtu Khayrkhan Ula Mts,

g — Ala-A (*1—2*) and Pericline (*2—3*) twins of secondary albite; Permian trachybasalt from Lubiechowa, Kaczawa Mts

Orientation of feldspar b-g ⊥ [010]; An-content for structurally intermediate plagioclase corresponding to *σ-PCP* of secondary albite is given in parantheses in Figs *d-g*; arrows indicate position of α'-vibration direction respective to the trace of (001) cleavage

following values of the Euler I angles (Burri 1956; Burri, Parker & Wenk 1967), which are mean values of 3 measurements:

Φ — 81.2°	—	An_{48};	89.4°	—	An_8
Ψ — 59.0°	—	An_{42};	108.0°	—	An_0
Θ — 53.1°	—	An_{43};	81.6°	—	An_7.

The established anorthite contents in the same plagioclase on the basis of three Euler I angles show a slight scattering: in andesine An_{42-48} and in albite An_{0-8}.

The composition of those plagioclases established on the basis of extinction angles $\alpha' \wedge (010) \perp [100]$ is as follows: andesine An_{43} (28.6°) and albite An_0 (—18°). Differences in anorthite content established on the basis of Euler I angles may be due to the variability of the structural state (Burri 1956) and to the universal stage errors.

In Fig. 6b, a phenocryst of andesine is shown which is partly replaced by albite. Both feldspars have common twin axis and composition plane [100]/(001) of Ala-A law, and twinning axis and composition plane [010]/(001) of Pericline law with $\sigma = 0°$ angle or of Acline-A law. Fig. 6c shows Pericline twinning common for oligoclase and albite replacing oligoclase.

The (001) plane as a rule is the composition plane in Ala-A twins of primary plagioclase and secondary albite developed at its expense. Quite exceptionally, in only one Ala-A twin of an andesine phenocryst, the rhombic section 0kl (the trace of which forms with 001 one an angle of 6°) was found to be the composition plane (Fig. 7). Such a peculiar and extraordinarily rare type of Ala-A twinning has not been known so far in plagioclase, but its possibility was theoretically predicted by Franke (1920). According to his calculations, the difference in position of that plane in albite and anorthite should be about 7°.

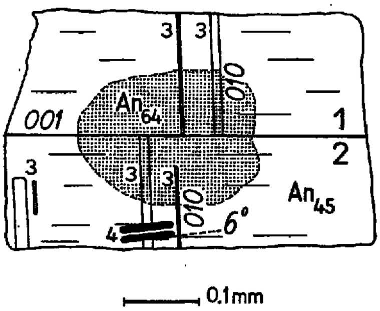

Fig. 7. Ala-A twins in zoned plagioclase from the Permian trachybasalt at Krajanów, Inner--Sudetic Trough; orientation ⊥ [100]
1—2 — Ala-A twin, in which composition plane is (001), 3—4 — Ala-A twins (two black lamellae), in which composition plane is the rhombic section 0kl; the angle between the traces of rhombic section and of (001) is 6°; 1—3 and 2—3 — Albite twins

The replacement of primary plagioclase by secondary albite retaining the twinning structure is a common phenomenon in all investigated volcanic rocks from the Sudetes, Fore-Sudetic Monocline, Western Pomerania, and Western Mongolia. The same manner of albitization is known to occur in andesine An_{30-35} grains of the Cambrian tuffs of the Upper Altay Mts and West Sayans Mts (Reverdatto 1960). A similar phenomenon has been reported as well by Rusinov (1965, 1968) from the Tertiary and Quaternary propilitized tuffs and dacite-andesite lavas of Kamchatka: in these rocks, basic plagioclase (andesine-bytownite) twinned according to Albite law were replaced by albite which retained the original twinning.

It is worth noting that Pericline twins are to be found in the plagioclase (oligoclase, andesine) of rhyolites, rhyodacites, and dacites. In basalts, trachybasalts, and latites, the primary plagioclase (andesine-bytownite) and the albite that replaces them are only sometimes twinned according to Pericline law with a composition plane which does not coincide with the (001) face. Much more common are multiple twins with (001) composition plane and [010] twin axis. They are either Acline--A twins or a particular case of Pericline twinning with the composition plane (001). Twins with [010] axis and (001) composition plane are to be found also in albite pseudomorphs after oligoclase and andesine of some acid volcanic rocks (Tables 2—4).

In plagioclase of intermediate state of ordering (to which, as we shall see, belongs most of plagioclase of volcanic rocks), the concordant position of *RS* and (001) planes may occur only at the composition close to An_{42} (Burri, Parker & Wenk 1967). In plagioclase of other composition, it is hardly probable that *PCP* is parallel to the (001) plane, hence the above-described twins of [010]/(001) type are likely to be Acline-A ones.

The secondary albites An_0 from albitized granodiorites of the Strzegom--Sobótka massif are usually twinned according to Albite and Pericline laws and in some cases according to the Carlsbad, Ala-A and Ala-B laws. Their Pericline twins were inherited after plagioclase that was primarily rich in anorthite and was zonal, as evidenced by the variable orientation of *PCP* within individual albite grains. The σ_{PCP} angles in central parts of the albite are usually smaller than in their outer parts, thus indicating that, prior to albitization, the cores of those feldspars were richer in anorthite than their outer rims (Fig. 8*a*—*c*). Such orientation of *PCP* in these albite grains imply that the composition of the primary plagioclase corresponding to andesine and oligoclase was very close to that of the plagioclase of unaltered granodiorites (Table 5).

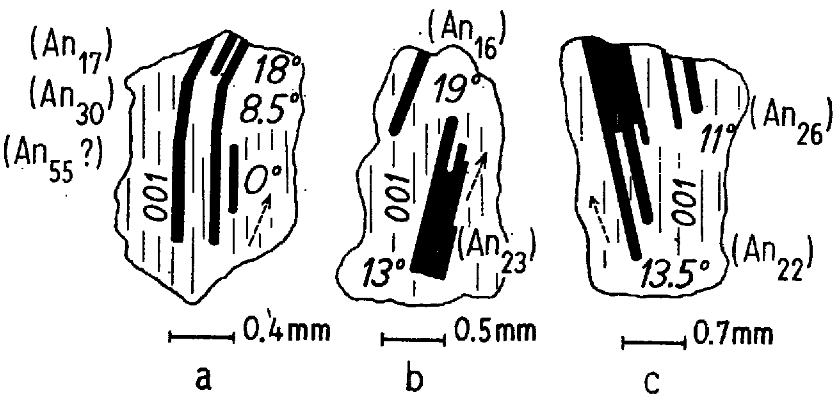

Fig. 8. Relic Pericline twinning (black lamellae) in albite pseudomorphs (An_0) after primary zoned plagioclase grains from altered granodiorites of Strzeblów (Strzegom--Sobótka massif); orientation ⊥ [010]; An-content for ordered plagioclase corresponding to the σ-*PCP* of secondary albites is given in parentheses; arrows show position of the α'-vibration direction respective to the trace of (001) cleavage

Other twinning, such as the Albite, Carlsbad, Ala-A and Ala-B, was probably inherited by the albite from primary plagioclases of the unaltered granodiorites.

POSITION OF PCP IN SECONDARY ALBITE IN RELATION TO THE *An*-CONTENT AND (*Al*, *Si*)-ORDERING OF THE PRIMARY PLAGIOCLASE

Pericline twins of secondary albites inherited after oligoclase and andesine are single or multiple in the investigated acid rocks (Fig. 6; and Pl. 2, Fig. 2; Pl. 3, Fig. 1). The single form of these twins and the frequently observed variation in width of the multiple lamellae are, according to Vance (1961), morphologic features typical of growth twins. Both forms of Pericline twinning of identical σ_{PCP} angles have been found in albites from the same rhyolite samples.

A small σ_{PCP} angle is characteristic of Pericline twins. It usually ranges from 0° to 6.5°, and sporadically is −3° (in albite replacing labradorite from a Permian trachybasalt, Fig. 6*g*; and Tables 2—4). If the secondary origin of the investigated albites had not been known, one might have inferred that small values of σ were indicative of crystallization of feldspars in disordered state, and that the common, ordered state was secondary. Such an inference could have been based on the following observations:

1. Albite, particularly in rhyolites, frequently occurs in association with soda--sanidine ($2V_a \perp 010 = 10$—$45°$).

2. There is a distinct dependence between the σ angle and the structural state of albite — the fact proved experimentally (Fig. 9). According to Barth & Thoresen (1965) and Barth (1969), a rhombic section, the position of which in a nonheated authigenic albite as defined by σ angle was 30°39′, changed its orientation after 10 days of heating, attaining a value of $\sigma = -4°23'$.

3. Of all the plagioclases, synthetic, disordered albites An_0 are easiest to transform into ordered forms (Eberhard 1967).

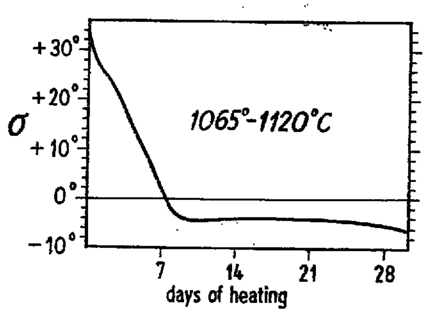

Fig. 9

Variation of rhombic section position (expressed by σ) in heated albite (redrawn from Barth & Thoresen 1965)

It follows from Fig. 9 that the σ_{PCP} angles observed in the investigated albites (from —3° to 6.5°) may be attained by pure ordered albite after 7—10 days of heating at temperatures of 1065—1120° C. If one assumed that the position of *RS* in the albite was controled by temperature only, one would be led to regard it as a high-temperature variety, and that, in turn, would imply an igneous origin. As will be shown below, the secondary origin of such albite is beyond any doubt, and the σ_{PCP} angle depends entirely on the composition of the primary plagioclase of intermediate ordering state.

Despite careful examination of about 800 samples of various acid volcanic rocks, only 3 phenocrysts of primary plagioclase have been found that were Pericline twinned, and even those were highly albitized. Because of their particular importance for the problem of inheritance of *PCP* by secondary albite, their characteristics are given in detail as follows:

1. In a Permian rhyolite from a quarry at Sokołowiec (*1* in Fig. 1), an albite phenocryst with relicts of oligoclase An_{23} has been found (extinction angle: $\alpha \wedge 001 \perp \gamma = 5°$); the oligoclase and albite portions are Pericline-twinned and show identical σ_{PCP} angles 4.6° (Fig. 6*c*). Such an angle is indicative of an intermediate ordering state of oligoclase of the given composition (point *1* in Fig. 10). At another

site of the same rhyolite extrusive body (Różana village), relict primary plagioclase and secondary albite An_0 have been encountered juxtaposed in the same sample. The primary plagioclase shows a composition of An_{32} and An_{38} (extinction angles: $\alpha' \wedge 010 \perp [100] = 21.5$ and $26°$ respectively), and in the secondary albite the σ_{PCP} is 2.3—2.5°, which at an intermediate ordering state would correspond to the mentioned compositions of primary plagioclases (points *A* and *B* in Fig. 10).

2. An andesine phenocryst An_{30} (extinction angle: $\alpha' \wedge 001 \perp \gamma = \sim 0°$) occurring in a Cambrian rhyodacite from Western Mongolia (*1* in Fig. 3). It is a single Manebach twin with perfectly developed Pericline lamellae with σ_{PCP} angle 4.4° indicative, at the mentioned composition, of an intermediate ordering state (point *2* in Fig. 10). In the same sample occur phenocrysts of andesine An_{30} oriented $\perp$ [100] (extinction angle: $\alpha' \wedge 010 = 20°$). The axial angle $2V_\alpha$ is 83.5°, which also suggests an intermediate ordering state of the andesine. Other samples from that and nearby exposures contain only albite An_0 phenocrysts which are frequently Pericline-twinned. The σ_{PCP} angles are 4—4.5°, values which, at assumed intermediate ordering state, corresponds to the composition of primary plagioclase An_{27-29}.

3. In an Upper Carboniferous rhyodacite from Czarny Bór (*6* in Fig. 1), a phenocryst of andesine An_{42} partly replaced by albite An_0 has been found (Fig. 6*b*). The composition of this feldspar has been established on the basis of optical orientation of an Ala-A twin and an extinction angle $\alpha \wedge (001) \perp \gamma = -12°$. The optics of the andesine corresponds to the high-temperature series ($2V_\alpha = 86°$). It contains thin, probably Pericline lamellae with a composition plane (001), $\sigma_{PCP} = 0°$[5], which points to an intermediate ordering state (point *3* in Fig. 10).

Relation between the composition, (*Al, Si*)-ordering and σ angle in the plagioclase series is shown in Fig. 10. This diagram is based on the σ_{RS} angles calculated for 105 ordered and disordered plagioclases (Starkey 1967). Most of these feldspars are disordered due to heating. The beginning of the variability curve for the ordered plagioclases (*O*) has been slightly modified by the present author assuming σ angle 37° instead of 34°. The value of 37° has been found in pure albite from an albitic granodiorite of the Česka Čermna Massif (Fig. 16*b*).

In the diagram, the data points *1*—*3*, *A* and *B* of the studied relict plagioclases from volcanic rocks plot along a line in the middle of the field bounded by curves for extremely low-temperature (*O*) and high-temperature (*D*) plagioclases. From the position of those points it appears that the orientation of *PCP* in the volcanic relict plagioclases at a given composition always corresponds to an intermediate ordering state of the structure. Thus the σ angle of secondary albite that inherit *PCP* from primary plagioclase in volcanic rocks may be used as an indicator of the composition of the primary plagioclase in relation to the intermediate ordering state of its structure.

The observations carried out so far by many authors prove that in the plagioclases of volcanic rocks the intermediate ordering states are most common (Karl 1954; Burri 1956; Gottardi 1962; Slemmons 1962 and others — *see* Tröger 1969, p. 718). These observations are in agreement

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[5] At the composition of An_{42}, *PCP* coincides with (001), although an Acline-A twinning can not be excluded (Burri, Parker & Wenk 1967).

with some older data pertaining to the σ_{PCP} values and the composition of various plagioclases (Schmidt 1919). In Fig. 10, the results form an almost straight belt corresponding to the intermediate state of the structure. The

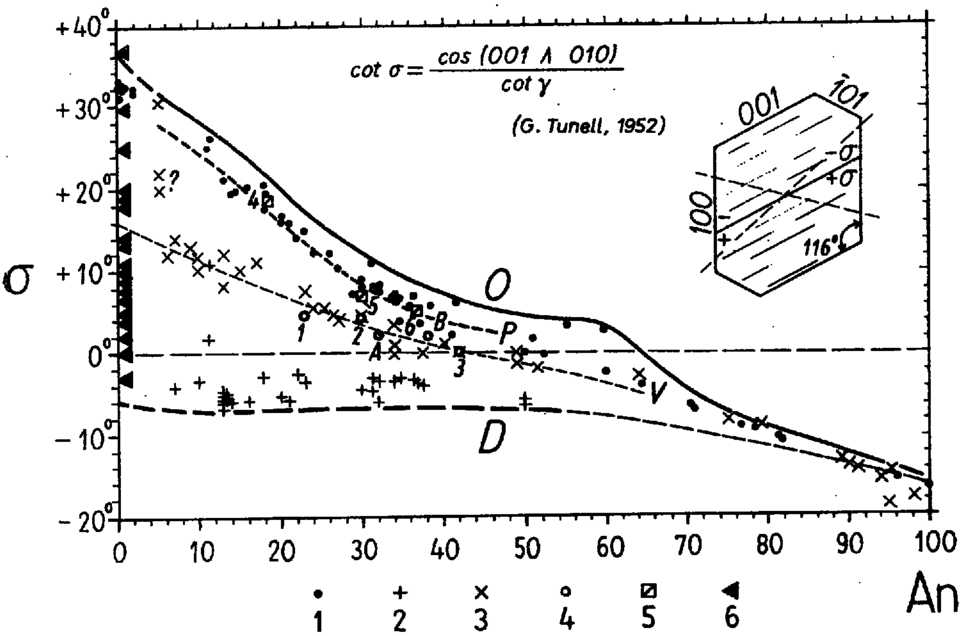

Fig. 10. The σ-angle variation of rhombic section (*RS*) and of pericline composition plane (*PCP*) with An-content and structural state of plagioclase series

O, *D* — curves showing variation of σ-*RS* calculated from cell dimensions of highly ordered (*O*) and disordered (*D*) plagioclases (redrawn from Starkey 1967, Fig. 1),

P — curve showing variation of privileged σ-*RS* in plutonic plagioclases (based on Starkey's data),

V — curve presenting variation of σ-*PCP* in structurally intermediate plagioclases (data partly taken from Schmidt 1919),

1, *2* — calculated σ-*RS* of ordered (*1*) and disordered (*2*) plagioclases (plotted from Fig. 1 of Starkey 1967),

3 — observed σ-*PCP* in natural plagioclases (taken from Schmidt 1919),

4—*5* — observed σ-*PCP* in primary plagioclases of Sudetic and Mongolian volcanic (*4*) and granitoidic (*5*) rocks,

6 — observed σ-*PCP* in albites (An_0) of volcanic (chiefly from ~0° up to 6.5°) and granitoidic (chiefly > 5°) rocks from the Sudetes Mts and Khasagtu Khayrkhan Ula Mts

relicts of primary plagioclases from volcanic rocks examined by the present author lie within that belt. The *V*-line drawn as the median line of that rather narrow belt expresses the privileged ordering state of structure of the volcanic plagioclases. The studied primary relict plagioclases of the volcanic rocks plot almost exactly on that line and fix its run at the composition range of An_{23-42}.

The *V*-curve (Fig. 10) served to deduce the primary composition of plagioclases on the basis of σ_{PCP} angles of albites that replace those plagioclases (Tables 2—4). The primary composition of albites as read from σ angles (Fig. 11) demonstrates that in the acid volcanites studied by the author the 0—6.5° range of the σ_{PCP} angles in secondary albites corresponds to the composition of An_{22-42} of primary plagioclases. Studies of primary relict plagioclases revealed an almost identical composition

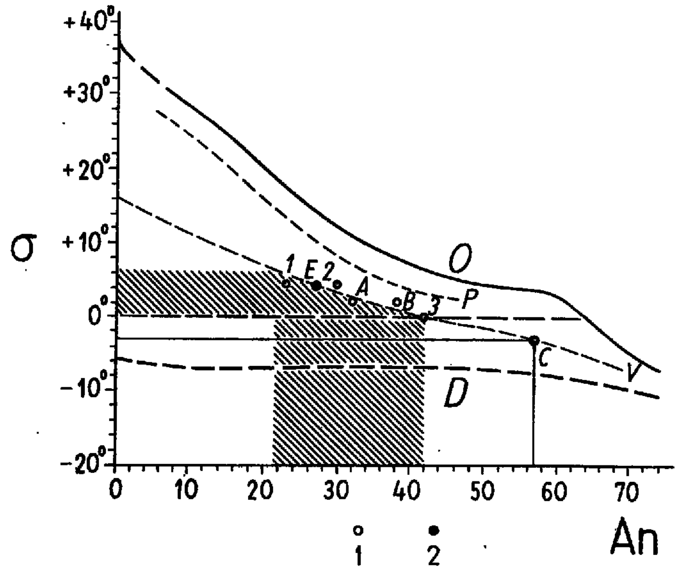

Fig. 11. Approximate An-content of primary plagioclases resulting from the σ-angle of relic pericline composition plane (*PCP*) of metasomatic albites occurring in volcanic rocks from the Sudetes Mts and Khasagtu Khayrkhan Ula Mts

1 — *σ-PCP* of relic plagioclases preserved in altered rhyolithes and rhyodacites,
2 — *σ-PCP* of metasomatic albites replacing primary plagioclases in trachybasalt (C) from Lubiechowa in the Kaczawa Mts and rhyodacite (*E*) from Stara Białka, Inner Sudetic Trough; other explanations as for Fig. 10

range. If the studied albites were regarded as primary feldspars, all the mentioned acid volcanites should have been classed as alkali rhyolites. But the reconstruction of the composition of primary plagioclases shows that the systematic position of those rocks prior to albitization was different and that they belonged to normal rhyolites, dellenites, rhyodacites and dacites. Hence, the deduced primary composition of the plagioclases may serve as a basis for establishing the original systematic position of the albitized volcanic rocks.

Feldspars of the altered Carboniferous rhyodacites at Stara Białka (Table 2, No. 4) illustrate well the usefulness of the *V*-curve for the reconstruction of the primary composition of plagioclase on the basis of σ_{PCP} angles in secondary volcanic albite. A Pericline-twinned phenocryst of albite An_0 of σ_{PCP} angle = 4.5° has been found in the southern corner of the massif of those volcanites and, according to the *V*-curve (point *E* in Fig. 11), this value corresponds to plagioclase An_{27}. A similar composition has been recognized in a relict phenocryst of a zoned plagioclase (core An_{31}, rim An_{21}) preserved in a rhyodacite from the northern margin of that massif.

The *V*-curve provides good results also when applied to albite replacing the anorthite-rich plagioclase of intermediate volcanic rock. An albite An_0 lath of σ_{PCP} angle $-3°$ (Fig. 6*g*) has been found in the upper part of a flow of the albitized trachybasalt at Lubiechowa (Fig. 2). According to the *V*-curve, this angle corresponds to a primary plagioclase An_{57} (point *C* in Fig. 11). A very similar composition An_{53-65} was found in laths of an almost unaltered labradorite from the lower portion of the same lava flow.

The shape of the *O*- and *D*-curves (Fig. 10) shows that the effect of the ordering state on the position of *RS* decreases rapidly with increasing *An*-content in plagioclase. However, the practical significance of this dependence for the reconstruction of the composition of primary plagioclase on the basis of σ_{PCP} angle of the secondary albite appears to be very limited, mainly because the primary basic plagioclases and the secondary albites developing at their expense in the examined basalts, trachybasalts and diabases most frequently show Acline-A twinning. Such twins, which (according to Burri, Parker & Wenk 1967) cannot be distinguished from the complex Ala-Manebach ones with twin axis $\perp$ [100]/(001), have also been noted in the zoned plagioclases, *e.g.* $An_{67-45-27}$ and $An_{80-69-44}$.

When reconstructing the composition of primary plagioclase on the basis of the σ_{PCP} angle of the albite replacing it, one should consider that the *(Al, Si)*-ordering of the primary plagioclase in plutonic rocks was higher than that of the volcanic plagioclase. This applies, in particular, to acid plagioclase in which the effect of ordering onto the position of *RS* is much greater than in strongly basic ones (curve *O* in Fig. 10).

The data available show that the plagioclases of plutonic rocks usually exhibit an intermediate, but clearly close to the maximally ordered structural state (Gottardi 1961, 1962 and others — *see* Tröger 1969, p. 718). These plagioclases are represented on the Starkey's plot (Fig. 10) by a narrow belt of points bounded by the curve (*O*) of the variability of the σ_{RS} angle in the most ordered plagioclases. Positions of those points are determined by calculated σ_{RS} values for the ordered plagioclases of a given *An*-content (Starkey 1967). Within this belt plot the points *4*—*6* of the examined primary plagioclases from unaltered granodiorites of Strzeblów (Table 5, No. 1). In these plagioclases, the σ_{PCP} angles are in agreement with the calculated values of σ_{RS} of Starkey's plagioclases of similar composition.

Plagioclases of plutonic rocks are evidently grouped in a narrow belt (Fig. 10) through which a median line *P* is drawn that expresses the privileged structural ordering state in plutonic plagioclases. This curve serves to establish the composition of the primary plagioclases on the basis of σ_{PCP} angles of secondary albites An_0 of the altered granodiorites from

Strzeblów, Chwałków and Żółkiewka (Table 5). It may be seen (Fig. 12, *open circles*) that the primary composition of plagioclases replaced by albite in those rocks was An $_{9-38}$, the range being fairly similar to the

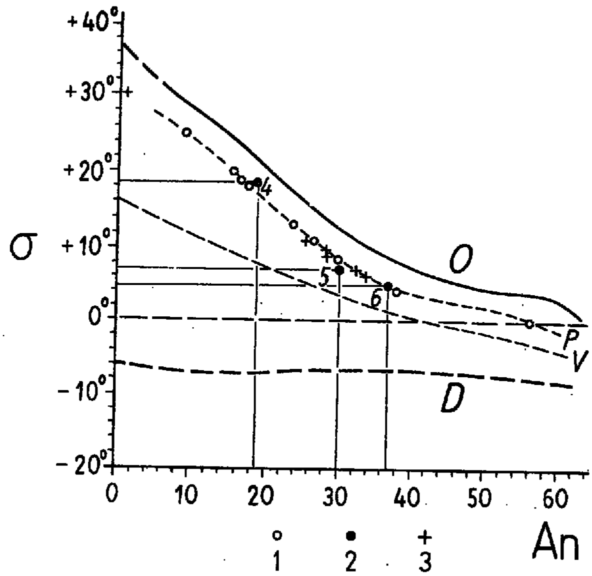

Fig. 12. Approximate An-content of primary plagioclases resulting from the σ-angle of relic pericline composition plane (*PCP*) in metasomatic albites of altered granodiorites from the Strzegom-Sobótka massif

1 — σ-*PCP* of secondary albites from altered granodiorites of Strzeblów and Chwałków,
2 — σ-*PCP* of primary plagioclases from unaltered granodiorites of Strzeblów,
3 — σ-*PCP* of secondary albites from the Żółkiewka granodiorite
Other explanations as for Fig. 10

variability of the composition of primary plagioclases An_{0-38} from unaltered granodiorites (Table 5, No. 1). Sometimes these zoned plagioclases are surrounded by thin rims of pure, probably primary albite, but unfortunately it was impossible to determine the σ_{PCP} angles in the rims.

In central parts of some secondary albite grains, the σ_{PCP} angle is 0° (Fig. 8*a*), which with reference to curve-*P* points to a composition of plagioclase An_{56} (Fig. 12, *open circle*). Such a composition was not encountered in the plagioclase of the unaltered granodiorite of Strzeblów and Chwałków, whereas in other outcrops of the Strzegom-Sobótka massif (*e.g.*, at Graniczna) some cores of the zoned plagioclase have composition An_{50}. Thus, it seems likely that some zoned plagioclase of the granodiorite from Strzeblów and Chwałków might have contained cores richer in anorthite prior to albitization. It is also possible that, during the initial stage of crystallization of the feldspars in question, when the temperature was higher, the plagioclases which formed the cores could have had a lower ordering state (*e.g.*, such as expressed by *V*-curve in Fig. 10). Then the angle $\sigma = 0°$ would correspond to composition An_{42} — a value fairly close to An_{38} observed in the cores of plagioclase from unaltered granodiorite of Strzeblów and Chwałków.

By means of the *P*-curve, the primary composition of plagioclase from the albitized portion of the Żółkiewka granodiorite has been also defined. The σ_{PCP} angles of albite An_0 (Table 5, No. 2) replacing the primary plagioclase correspond to composition within the range of An_{1-33} (Fig. 12, *crosses*) which is similar to the composition range of the primary plagioclases An_{0-21} from the unaltered portion of the granodiorite. Also, around these feldspars thin rims occur, most probably of primary almost *An*-free albite.

EXAMPLES OF RECOGNITION OF SECONDARY ALBITES IN VARIOUS IGNEOUS ROCKS

In previous chapters the albite pseudomorphs were discussed, the secondary origin of which was indicated by:

1. Relicts of primary plagioclases,
2. Gradual or direct transition from altered rocks to the albitized ones, with preservation of primary texture and fabric.

It is well known from petrographic descriptions of albitized igneous rocks that plagioclases are usually replaced completely by albite of normal habit of twinning [6], inherited from primary plagioclase. Potassium feldspars, on the other hand, show greater resistance to albitization, and are usually only partly replaced by chessboard albite. Where no relicts of primary feldspars have been preserved, and where there are no secondary calcium minerals developed at the expense of the plagioclase (epidote, calcite, zeolites, etc), the recognition of the secondary nature, particularly of normal albite, may be very difficult. For example, the origin of albite in spilites and keratophyres is controversial: it is regarded as primary by some authors, or as secondary by others.

So far, all the petrographers studying albitized granitoid rocks in the Sudetes have ascribed a primary origin to the normal albite. The recognition of albitization symptoms in such rocks was based on only one criterion, which was the partial replacement of potassium feldspars by chessboard albite. The diagnostic significance of the position of *PCP* in normal albites is demonstrated below, not only for unmetamorphosed rocks, but also for those showing slight epimetamorphic changes.

PLAGIOCLASE OF THE IZERA LEUCOGRANITE (WESTERN SUDETES)

The albitized and leucocratized granite-gneisses of the northern slopes of the Kamienica Range in the Izera Mts (Western Sudetes) were named leucogranites by K. Smulikowski (1958). These rocks occur along the northern contact of the Izera

[6] Farther on in this paper, such albite is referred to as normal albite.

gneisses with a narrow belt of crystalline schists stretching roughly parallel through the whole gneissic block of the Izera Mts. The main outcrops of the leucogranites are to be found near Czerniawa, Świeradów Zdrój, Kotlina, Proszowa, Kwieciszowice, and Mała Kamienica (*12—16* in Fig. 1).

According to K. Smulikowski (1958) the Izera orthogneisses belong to the granitic intrusion of Pre-Caledonian age, which was subjected to epizonal cataclasis of varying intensity and slight postdeformational recrystallization. In the contact zone with the crystalline schists, the orthogneisses are frequently albitized, and enriched in tourmaline believed to have originated from deep emanations rich in sodium, boron, and fluorine. According to W. Smulikowski (1972), some leucogranites of the Izera Mts form small intrusive bodies of originally very light-colored granitic rocks.

K. Smulikowski (1958), as well as successive authors (Kozłowska-Koch 1965; W. Smulikowski 1972), distinguished in the leucogranite two genetic types of albite: primary and secondary. The normal habit of twin lamellae was considered to be diagnostic for the primary albite, while the typical chessboard albite, which developed at the expense of microcline, was regarded as secondary. These observations were supplemented by K. Kozłowski (1974), according to whom a part of the chessboard albite in the leucogranite originated from the normal albite. He also suggested that the normally twinned albite could have developed in some places from the chessboard albite. So far, replacement of microcline by chessboard albite has been the only criterion for the recognition of sodium metasomatism in these leucogranites.

Below are presented the results of examinations of normal albites from about 50 samples of leucogranites collected by Dr. Ł. Karwowski. The chessboard albites of these rocks are described in the next chapter.

The normal albite in almost undeformed leucogranites forms subhedral tabular crystals (Fig. 13*a*; and Pl. 3, Fig. 3), and in varieties more cataclazed, it forms anhedral grains. Very fine laths of poikilitic albite enclosed in large grains of secondarily perthitized microcline, or in chessboard albite pseudomorphs after microcline, show the highest automorphism (Fig. 13*b*). The microcline grains, when

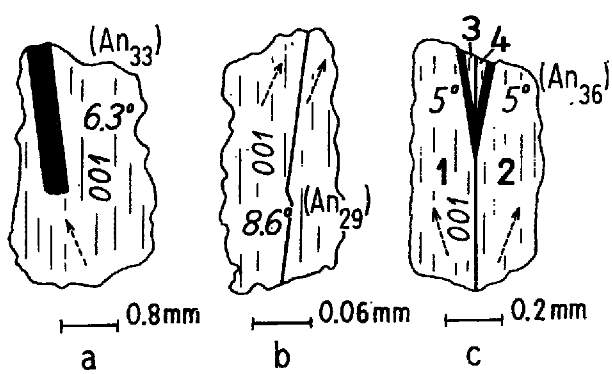

Fig. 13. Relic twinnings in albite pseudomorphs (An_0) after primary plagioclases of granitoids from the Sudetes Mts and Khasagtu Khayrkhan Ula Mts; orientation $\perp$ [010]

a, b — simple Pericline twins (*b* presents a small inclusion of albite in strongly albitized microcline grain); Izera leucogranite from Kopaniec,

c — Ala-A (*1—2*), Manebach (*3—4*) and Pericline (black lamellae) twins; adamellite of the Boro-nuru massif, Western Mongolia

In parentheses is given An-content in ordered plagioclase corresponding to the σ-*PCP* of secondary albites; arrows show position of the α'-vibration direction respective to the trace of (001) cleavage compared with normal albite, are usually larger, and are replaced by chessboard albite to various extents up to complete pseudomorphosis (Pl. 6, Figs 1—2).

The optical properties of the albites in question (Table 8, No. 4) invariably indicate an almost complete lack of anorthite admixture, and the $2V\gamma$ angles 76—81° correspond (*cf.* Fig. 5) to a maximum index of ordering (*I.I.* = ~ 90—100).

The normal albites are usually twinned according to Albite, Pericline, and sometimes Carlsbad laws. The Pericline twins are single or multiple, and do not exhibit features of deformation twins (Fig. 13*a*, *b*; and Pl. 3, Figs 2—3). Albites of all the investigated leucogranites most often have σ_{PCP} angles from 7° up to 9°, sometimes 5°. Higher σ_{PCP} angles attaining 10° were encountered in some albites of the leucogranites of Kopaniec. Albites with σ_{PCP} angles 6.3° and 8.6° also occur there (Fig. 13*a*, *b*).

Without any doubt the albites of a composition $\sim An_0$ and of ordered structural state could not attain such low σ values by direct crystallization, because in such a case the position of the *PCP* would be defined by a σ angle about 30° (Fig. 14). The determined σ angles prove that, in fact, the *PCP* of the albites studied (58 Pericline twins) corresponds (Fig. 14, *open circles*) to primary plagioclase of a composition An_{27-37}. Thus, the normally twinned albites are secondary, and have developed at the expense of oligoclase and andesine — plagioclases typical of granitoids in unaltered state. The lack of σ_{PCP} angles of about 30° (corresponding to ordered albite) suggests that none of the albites examined was subjected to recrystallization during later dynamic deformations.

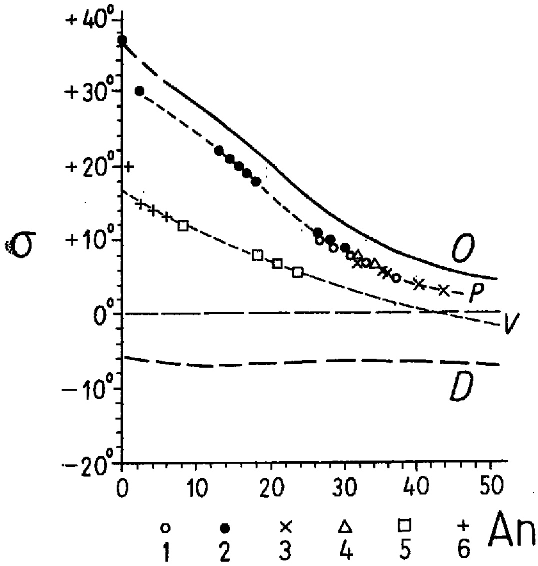

Fig. 14

Approximate An-content of primary plagioclases resulting from the σ-angle of relic pericline composition plane in metasomatic albites from albitized granitoids

Host rocks: *1* — Izera leucogranites, *2* — albite granodiorites from Brzozowie and Česka Čermna, *3* — adamellites of the Boro-nuru massif, Western Mongolia, *4* — syenodiorite from Niger, *5* — vein grano-diorite from Strzelin, *6* — aplogranite from Garby Izerskie; other explanations as for Fig. 10

The proportions of quartz, albite pseudomorphs after primary oligoclase and andesine and after microcline show that, prior to their albitization, the investigated leucogranites had the mineral composition of adamellite and granodiorite.

PLAGIOCLASE FROM ALBITE GRANODIORITES OF THE ČESKA ČERMNA MASSIF (CENTRAL SUDETES)

A small massif of albitized granodiorites occurs in the Central Sudetes at the following localities in Czechoslovakia: Česka Čermna, Dobrošov and Nový Hradek (Fig. 15). These rocks are petrographically very similar to the leucogranites of the

Izera Mts. The granitoids, referred to as leucocratic albite granodiorites, are believed to be a Caledonian intrusion in Algonkian phyllites (Dudek & Fediuk 1956). The same rocks crop out in the Polish part of the massif near Brzozowie, and they were classed as alkali granites (Borkowska 1959). According to the cited authors, albitization is indicated in these rocks by far-advanced substitution of chessboard albite for microcline, the process having been facilitated by cataclastic deformations. Another kind of albite which is normally twinned was regarded as primary feldspar.

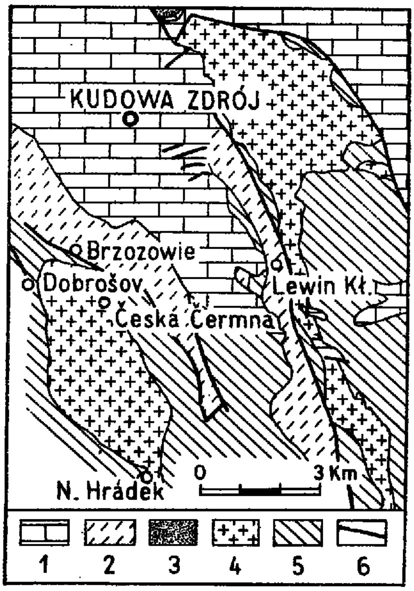

Fig. 15

Geological map of Variscan granitoids in the vicinity of Kudowa Zdrój (*after* Rode 1934; modified)

1 — Cretaceous deposits, 2 — Rotliegendes deposits, 3 — Upper Carboniferous deposits, 4 — Variscan granitoids, 5 — mica schists and phyllites, 6 — faults

Below, characteristics are presented of normal albites from the Česka Čermna granodiorites sampled at Brzozowie, Česka Čermna, and Dobrošov. The specimens from the last two sites come from the collection of Professor K. Smulikowski. Albite of those rocks occurs in the form of subhedral laths and anhedral grains up to 5—6 mm in size, which exhibit optical characters of almost pure *Na*-feldspar (Table 8, No. 2). The optic axial angle $2V\gamma$ 79—84° indicates an intermediacy index *I.I.* = 90—100 according to the Slemmons' diagram (Fig. 5).

The albites here are frequently twinned according to Albite and Pericline laws, and form combinations with the Carlsbad and Ala-A twins. Pericline twins are single or multiple (Fig. 16). Their lamellae do not show features of deformation twins. The Pericline twins are characterized by a variable position of the *PCP*, which most frequently does not correspond to the orientation expected for pure ordered albite (σ angle 30—37°). The σ_{PCP} angles measured in 32 albite grains fall into two groups: 9—11°, and 18—22°. A composition of primary plagioclase An_{27-30} corresponds to the former, and a composition of An_{13-18} to the latter (Fig. 14, *filled circles*). This means that the general composition of primary plagioclases in the investigated granodiorites corresponds mainly to the oligoclase member.

A higher σ_{PCP} angle in the marginal parts of grains is a characteristic feature of some Pericline-twinned albites (Fig. 16*b*, *c*), probably due to the primary differentiation of the anorthite in the particular plagioclase grains. On the basis of the σ_{PCP} angles (17° and 11°), it may be determined that, prior to albitization, the central parts of such grains was oligoclase (Fig. 14, *filled circles*). The σ_{PCP} angles

30° and 37° in their outer parts correspond to pure, or almost pure albite, which is most probably a primary feldspar formed during the crystallization of the granodiorite.

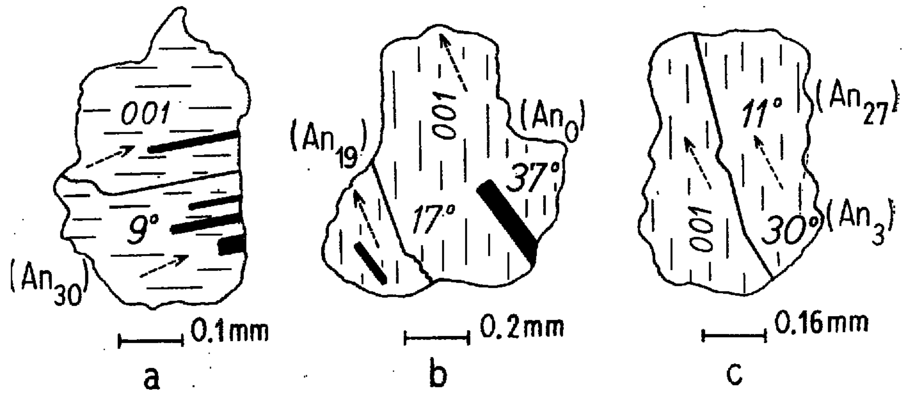

Fig. 16. Relic Pericline twinning (black lamellae) of secondary albites (An$_0$) in albite granodiorites from Brzozowie (*a*) and Česka Čermna (*b*, *c*); orientation ⊥ [010]
In parentheses is given An-content of ordered plagioclase corresponding to the σ-*PCP* of secondary albite grains; arrows show position of the α'-vibration direction respective to the trace of (001) cleavage

PLAGIOCLASE FROM GRANITOIDS OF THE KHASAGTU KHAYRKHAN ULA MTS (WESTERN MONGOLIA)

Albitized granodiorites with transitions to adamellites are known to occur in the Khasagtu Khayrkhan Ula Mts in Western Mongolia. The Boro-Nuru granitic massif of Salairian age is of particular interest. It occurs between the Duru-nur Lake and the Dzavchan Gol River (Fig. 3). It is a large plutonic intrusion adjacent to albitized Cambrian rhyodacites (S. Kozłowski 1969; Nowakowski 1969). Those rocks consist of subhedral albite An$_0$ grains (Table 8, No. 6) of normal twin habit, potassium feldspar partly replaced by chessboard albite, quartz, and completely chloritized biotite.

At first sight, the secondary origin of the normal albites is indicated by the scarce and very fine epidote inclusions. Pericline twins of these feldspars are frequently single and form combinations with the Ala-A and the Manebach twins (Fig. 13*c*). The σ_{PCP} angles usually are 5—7°, corresponding to the composition of primary plagioclase An$_{35-31}$ (Fig. 14, *points marked by "x"*). In some portions of the granodiorite, albite has been encountered which in its cores has σ_{PCP} angles 3—4°, and in the marginal part 6°. This indicates a zonal stucture of the primary plagioclase, with An$_{44-40}$ core and An$_{35}$ rim. No relict plagioclases have been found, but in the northern part of the Boro-nuru massif, granites rich in perthite and poor in oligoclase An$_{20}$ have been recognized.

PLAGIOCLASE OF THE SYENODIORITE FROM THE DJADO PLATEAU IN NIGER

A sample of albitized syenodiorite from the Djado Plateau in northern Niger, kindly given by M. Komacka, M. Sc., contains plagioclase represented by albite An$_0$ grains. Combinations of Pericline, Ala-A, and Manebach twins are frequent in them, and their morphological features are identical with those of the albites occurring in the previously described Mongolian granitoids (Fig. 13*c*). The σ_{PCP} angles are

7—8°, which, assuming the ordering characteristic for plutonic feldspar, indicates that the albite developed at the expense of andesine An_{32-34} (Fig. 14, *triangles on P-curve*). The potassium feldspar in this syenodiorite is only partly replaced by chessboard albite.

PLAGIOCLASE OF GRANITIC VEINS FROM STRZELIN (SUDETIC FORELAND) AND GARBY IZERSKIE (WESTERN SUDETES)

Albite An_0 pseudomorphs after primary plagioclase are common components of some white granitic veins occurring in the Variscan granitoids near Strzelin in the Sudetic Foreland. The veins, which seldom attain 30 cm width, are related to the "Q" fissures of Cloos (Olszyński 1972). The samples described below derive from the quarries situated west of Strzelin.

Normally twinned albites An_0 (Table 8, No. 3), strongly perthitized potassium feldspar, quartz, and almost completely chloritized biotite are the main minerals in these vein rocks. The marginal portions of the veins and the granitoid wall-rock are enriched in clinozoisite, prehnite, zeolites (among others laumontite), calcite, and scaly aggregates of strigovite. Tabular, subhedral crystals of albite are twinned according to Albite, Pericline, and sometimes Carlsbad laws. Thin and frequently single Pericline lamellae (Pl. 3, Fig. 4) are characterized by σ_{PCP} angles 6—8°, sometimes 12°; hence, they cannot be primary albites. The values of these angles (Fig. 14, *squares*) are shown on the V-curve for structurally intermediate plagioclases. One might expect the plagioclase of thin igneous veins to have preserved a higher--temperature structural state than those of plutonic massifs. Under this assumption, the σ_{PCP} angles would indicate a composition of primary plagioclase An_{18-24}, and less frequently to An_9. Probably the vein rocks here were originally granodiorites which by subsequent albitization attained the petrographic character of alkali granite.

An interesting vein of aplogranite, 30—40 cm across, has been encountered in the Garby Izerskie by Dr. Ł. Karwowski and Dr. A. Kozłowski (*17* in Fig. 1). The vein stretches horizontally for several tens of meters in hornfels exposed in the "Stanisław" quartz mine. According to the mentioned authors, this vein is related to the Karkonosze granite. The aplogranite consists of small, subhedral, tabular albite An_0 (Table 8, No. 5), microcline-perthite, and quartz. Muscovite flakes, chlorite pseudomorphs after biotite, and nests of hydrothermal chlorite in form of fine scales (?strigovite) occur subordinately. The albite grains are Albite- and Pericline-twinned. The σ_{PCP} angle in the albites is 20°, but only some tens of meters away, where the rock grades into a coarse-grained leucogranite, the angle decreases to 13—15°. Such a differentiation of the σ_{PCP} angles is difficult to interpret, as it is not known whether the albites differed in their structural state at a constant composition of An_0, or their composition was variable at a constant (*Al, Si*)-ordering of structure. If one assumed their ordering state to correspond to the V-curve (Fig. 14, *crosses*), the inferred primary composition would be within the range of An_0 to An_7.

The data presented show that, during albitization, the twinning of the primary plagioclases of various granitoid rocks has been preserved. This phenomenon must be quite common in nature, as it has been detected in various types of igneous rocks of various geologic ages in different regions of the world.

PLAGIOCLASE FROM SPILITES AND KERATOPHYRES OF THE KACZAWA MTS (WESTERN SUDETES)

An immense sequence of slightly metamorphosed geosynclinal volcanic rocks attributed to the Variscan cycle occurs in the Kaczawa Mts (Zimmermann 1935, 1936, 1941; Block 1938). Spilites metamorphosed to greenstones (Fig. 1), associated with keratophyres and diabases (H. Teisseyre 1951; Łydka 1958), are the main component of this sequence. The greenstones and diabases, according to K. Smulikowski (1957), are completely albitized basaltic rocks. According to Narębski (1964), the spilites represent a spilitic differentiate from the basaltic magma. The keratophyres are strongly albitized, and frequently silicified rocks (Ansilewski 1954). The greenstones, particularly those of *"pillow lava"* structure, show well preserved intersertal and amygdaloidal textures. The main components of those rocks are very fine laths of almost pure albite, chlorite, and epidote, and sometimes relict augite. Albite and (most probably) Acline-A twins are discernible only in the large, but scarce laths of albite An_0.

The mineral composition of the greenstone diabases from the vicinity of Świerzawa, Bolków (Nagórnik), and Świebodzice (Jaskulin, Radosna) is the same as that of the *"pillow lava"* greenstones. Numerous phenocrysts of albite An_0 are twinned according to Albite, Carlsbad, Ala-A, and (most probably) Acline-A laws. In habit and frequency of occurrence of the Acline-A twins, the albites of the investigated greenstones and diabases are identical to the albites and basic primary plagioclases of the Sudetic trachybasalts and the Mongolian basalts and diabases (Tables 3—4). This similarity leads to the conclusion that such twins with the composition plane (001) in albites of the Kaczawa greenstones and diabases are not Pericline twins with $\sigma_{PCP} = 0°$. This value on the *V*-curve for the volcanic plagioclases (Fig. 17, *open circle*) corresponds to a composition of primary plagioclase (An_{42}) which is too acid for rocks of the basalt type. The abundance of epidote inclusions in phenocrysts and in fine laths of albite seems to suggest a very basic character for the primary plagioclase of the Kaczawa greenstones and diabases.

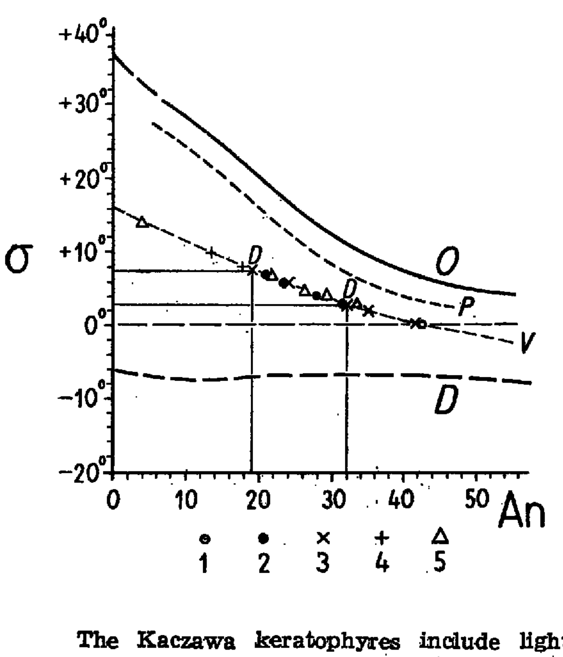

Fig. 17

Approximate An-content of primary plagioclases resulting from the σ-angle of relic pericline composition plane in metasomatic albites developed in greenstone-rocks and keratophyres

Host rocks: *1* — spilites and greenstone-diabases of the Kaczawa Mts, *2* — keratophyres of the Kaczawa Mts, *3* — quartz keratophyres of the Virgin Islands (*D* — plagioclases *An19* and *An32* coexisting with albites *An0*), *4* — keratophyres from Leszczyniec, *5* — Paczyn gneisses; other explanations as for Fig. 10

The Kaczawa keratophyres include light-colored volcanic rocks intensely fractured and albitized, the mineral composition of which corresponds to alkali rhyolite and trachyte rich in potassium feldspar or albite, the latter being sometimes associated with riebeckite (Ansilewski 1954; K. Smulikowski 1957). Albitic varieties of those rocks show secondary features and are due to albitization of dacites and rhyodacites (vicinity of Świerzawa and Sady Górne). Like some acid volcanic rocks of the Sudetes and Western Mongolia described in the present paper, the keratophyres contain phenocrysts of albite An_0 which is normally twinned and contains epidote inclusions, phenocrysts of potassium feldspar considerably replaced by chessboard albite, and in some cases quartz (vicinity of Kaczorów and Bolków). Completely albitized dacites contain only phenocrysts of albite An_0 enclosed in an ample rock mass consisting of grains of albite An_0, quartz, and epidote. The biotite phenocrysts in these rocks are replaced by chlorite with admixture of leucoxene and ferriferrous epidote.

The presence of Pericline twins with small values for the σ_{PCP} angle is a characteristic feature of the ordered, normally twinned albites in the Kaczawa keratophyres. Their lamellae are frequently single, as those shown in Fig. 6*d*, *e*, or they are combined with the Ala-A and Manebach twins (Pl. 4, Fig. 1). The σ_{PCP} angles, being close to the σ values of secondary albites of the Sudetic rhyolites and Mongolian rhyodacites (Tables 3—4), are usually 3—4° and 6—7°. The former σ values on the V-curve (Fig. 17, *full circles*) indicate the composition for the primary plagioclase An_{28-31}, the latter — plagioclase An_{21-23}. Both these compositions are very similar to those of the relict plagioclase of the Sudetic rhyolites and Mongolian rhyodacites (Tables 3—4).

A very similar range of σ_{PCP} variability was ascertained by Donnelly (1963) for ordered albites (Table 7, No. 3) from quartz keratophyres of the Virgin Islands. The value ranges from 0° to 6°, the most frequent being 2°. According to this author, such low σ_{PCP} values in ordered albite were caused by crystallization in an originally more disordered state. Phenocrysts of high-temperature oligoclase An_{19-32} partly replaced by albite were found by Donnelly in only one sample. In addition, few phenocrysts of albite An_0 of intermediate and ordered structural state were recognized. Donnelly explained the unusual occurrence of oligoclase in keratophyre by its assimilation of calcareous fragments of spilitic rocks. It seems more likely that the oligoclase is a relict as it was partly albitized and was associated with albite An_0 phenocrysts which were possibly of secondary origin. In composition, the oligoclase is strikingly similar to relict plagioclase of albitized rhyodacite and rhyolite from Sudetes (Tables 2—3), and albitized Mongolian rhyodacite (Table 4), as well as of the Permian porphyries from Bozen (Table 7, No. 8) examined by Karl (1954).

It is important to note that the σ_{PCP} angles 0°, 2°, and 6° reported by Donnelly for albite indicate an oligoclase-andesine composition, assuming their intermediate ordering state (Fig. 17, *points marked by "x"*). The deduced compositions are: An_{42}, An_{35}, and An_{24}. The An_{42} composition resulting from $\sigma = 0°$ rises some doubts as it is not certain whether we deal with a Pericline or Acline-A twinning. Two other compositions (*i.e.*, An_{35} and An_{24}) stand very close to that of a partly albitized oligoclase-andesine An_{19}—An_{32} of a keratophyre sample studied by Donnelly. These compositions correspond to values of σ_{PCP} 2.8° and 7° (Fig. 17, *points "x" marked by D*), which are very similar to σ 2° and 6° measured by Donnelly in the albites of the quartz keratophyres from the Virgin Islands.

All the above facts seem to suggest the secondary origin of albites in keratophyres both in the Virgin Islands and in the Sudetes.

PLAGIOCLASE FROM THE PACZYN GNEISSES AND QUARTZ KERATOPHYRES OF THE LESZCZYNIEC FORMATION (WESTERN SUDETES)

The metavolcanites of the Leszczyniec volcanic formation (?Upper Silurian) belonging to the eastern metamorphic cover of the Karkonosze granite are classed as spilitic-keratophyre rocks (Narębski & Teisseyre 1971; J. Teisseyre 1973). Low-

-grade metamorphosed volcanites known as the Paczyn gneisses[7] and quartz keratophyres (Fig. 1) are important members of this formation. The Paczyn gneisses, according to the cited authors, form small subvolcanic and hypabyssal bodies, and the keratophyres are effusive rocks. Both varieties of these metavolcanites from the western Sudetes abound in albite An_0 with inclusions of epidote and light mica and with quartz. Besides that, there are: hornblende similar to glaucophane, stilpnomelane, and chlorite. The mentioned authors are of opinion that the Paczyn gneisses and the keratophyres are products of solidification of trondhjemite magma of anatectic origin strongly enriched in sodium. This may imply the primary nature of the albite.

Albites from two varieties of the Paczyn gneisses distinguished by J. Teisseyre (1973), namely the fine grained gneisses from the Klatka quarry and the cataclastic gneisses and quartz keratophyres from the vicinity of Leszczyniec, are described below. According to that author, the primarily magmatic nature of the Paczyn gneisses is indicated by locally preserved doleritic texture (Pl. 4, Fig. 2). The interstices between the albite laths in these rocks are filled with quartz which, to a large extent, seems to have been secondarily introduced.

In weakly cataclazed gneisses, albite An_0 forms subhedral tabular crystals, whereas in the cataclastic variety the albites are strongly crushed. The composition of these feldspars corresponds to almost-pure *Na*-feldspar of ordering index *I.I.* about 90—100 ($2V\gamma$ = 76—86°; *cf.* Fig. 5). Epidote inclusions in albites are rare, light mica (probably developed by recrystallization of sericite) being more abundant. The edges of albite laths are devoid of such inclusions, which implies an external rim originally of almost pure albite (Pl. 4, Fig. 2). The twinning structure of these albites is diversified. Aside from abundant Albite and Pericline twins, combinations are common between these laws and those which according to Gorai (1951) are typical of magmatic plagioclases. These are Ala-A and Manebach twins (frequently developed exactly as in Fig. 6*f*), the latter being shown in Fig. 18*b*, and additionally Carlsbad- and sometimes Baveno twins. The single Acline-A twins were found only sporadically (Fig. 18*c*). The Pericline twins are multiple much more often than single: their lamellae show regular boundaries and varying width (Fig. 18).

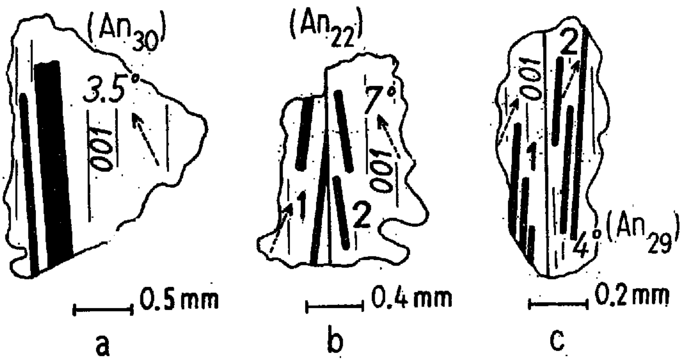

Fig. 18. Relic twinnings of albite pseudomorphs (An_0) after primary plagioclases from the Paczyn gneisses

a — Pericline twins (black lamellae), *b* — Manebach (*1*—*2*) and Pericline twins, *c* — Acline-A? (*1*—*2*) and Pericline twins

In parentheses is given An-content for structurally intermediate plagioclase corresponding to the *o*-PCP of secondary albites; arrows show position of α'-vibration direction respective to the trace of (001) cleavage

[7] "*Petzelsdorfer Gneis*" of Berg (1941).

Mechanical twins have not been found, even in albites of the most intensely cataclazed gneisses.

The σ_{PCP} angles usually are 3—5° (67 grains), sometimes 7° (9 grains). These values have been plotted (Fig. 17, *triangles*) on the V-curve of structurally intermediate plagioclases because of the volcanic origin of the Paczyn gneisses. From these plots one may determine that the primary plagioclases had the composition of An_{33-26} and An_{22}. A much higher σ_{PCP} angle 14° is shown only in the outer parts of some albite grains, whereas in their central portions it is 7°. Such a difference probably reflects the zoning of the primary plagioclases. Thus, it may be calculated that in their central parts they had a composition of oligoclase An_{22}, and in the rims of albite An_4. The albitization of the primary plagioclases in the Paczyn gneisses proceeded with the morphology and twinning of their grains left intact, which means that metamorphic recrystallization was not involved.

If albitization had involved epimetamorphic recrystallization, the twinning characteristic of igneous plagioclases would not have been preserved and feldspars poor in twins would have developed (Gorai 1951; Smith 1962). Epimetamorphic plagioclases originated as a result of blastesis should have ordered structures. Consequently, one may expect a σ_{PCP} angle about 30° in an ordered albite An_0, whereas the above reported values of σ_{PCP} 3—14° correspond on the P-curve (Fig. 17) to ordered plagioclases of An_{45-22} composition. Such plagioclases could not develop in epimetamorphic conditions. It follows from the orientation of *PCP* in the secondary albite that the plagioclases of the Paczyn gneisses were not subjected to blastic changes. On the other hand, primary mafic minerals were transformed into stilpnomelane, chlorite and amphibole of properties similar to glaucophane. Judging from the petrological properties, one may therefore deduce that the volcanic rocks represented now by the Paczyn gneisses have originally had a doleritic texture, and their dominant, or possibly only feldspar was plagioclase of oligoclase-andesine composition. Most probably their systematic position was close to andesite.

The albites of the quartz keratophyres from the vicinity of Leszczyniec exhibit almost the same optical properties and twinning as those of the Paczyn gneisses. At present these rocks consist almost entirely of albite An_0, quartz, and scarce chlorite pseudomorphs after biotite. The σ_{PCP} angles in albite phenocrysts are 8—10° (23 grains). On the V-curve (Fig. 17, *crosses*), these values correspond to An_{18-14} composition for primary structurally intermediate plagioclase, hence these plagioclases were poorer in anorthite than the primary feldspars of the Paczyn gneisses. This is probably why the keratophyre albites contain fewer epidote inclusions than albites of the Paczyn gneisses. Most probably the quartz keratophyres of the Leszczyniec formation originally were dacites with feldspars represented by oligoclase. These rocks in many textural details and mineral composition are very similar to the albitized dacite porphyries from the Fore-Sudetic Monocline and Western Mongolia (Tables 3—4).

CHESSBOARD ALBITES

The potassium feldspar of the volcanic rocks and granitoids described in this paper was evidently much more resistant to albitization than the plagioclase. Relicts of potassium feldspar are preserved even in those rocks in which the primary plagioclase has been completely albitized. The Permian rhyolite of the Fore-Sudetic Monocline (boreholes at Jany and Pomorsko) and the Izera leucogranite are the richest in chessboard albite among the studied rocks. In other rocks, chessboard albite is less common and is poorly developed.

In volcanic rocks, chessboard albite originated from sanidine ($2V_\alpha \perp$ $\perp$ 010 = 14–37°) of a composition of Ab_{20-40}, or from orthoclase ($2V_\alpha$ $\perp$ 010 = 56–65°). In the granitoids, on the other hand, it formed at the expense of microcline with typical cross-hatched twinning and high optic axial angle $2V_\alpha$ = 56–74°. The development of these albites consisted in the substitution of *Na*-atoms for *K*-atoms in the structure of potassium feldspars, which led to considerable changes in cell dimensions, particularly a_0, and b_0 as well as α and γ angles, especially in the case of sanidine (Table 9). In partly albitized potassium feldspar, the (010) plane

Table 9

Cell dimensions of alkali feldspars at room temperature (*from* Tröger 1969, Tab. 10, p. 654)

Feldspar variety	Composition	a_0 [Å]	b_0 [Å]	c_0 [Å]	α	β	γ
Sanidine	$K[AlSi_3O_8]$	8.60	13.04	7.17	90°	116.0°	90°
Microcline		8.57	12.96	7.22	90.65°	115.9°	87.65°
Low-albite	$Na[AlSi_3O_8]$	8.13	12.78	7.15	94.3°	116.65°	87.65°

is common for both feldspars, and the (001) planes differ in their orientation (Fig. 19). The directions [100] of both feldspars are also incompa-

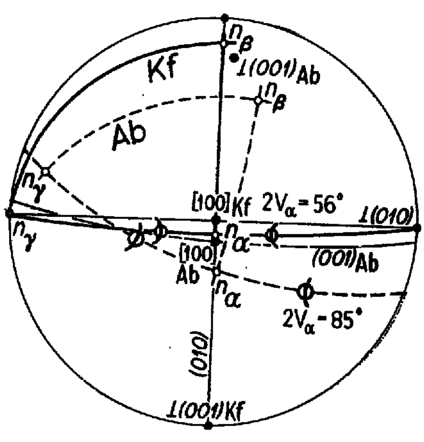

Fig. 19

Stereographic projection of the optic orientation of chessboard albite (*Ab*) intergrowing the K-feldspar (*Kf*); Permian rhyolite from the Rotliegendes of the Fore-Sudetic Monocline, borehole Pomorsko (depth 2873.6 m)

tible, and form an angle of 12–14°; but they coincide in secondary albites and in relict plagioclases within accuracy of the measurements by means of the universal stage.

OPTICAL PROPERTIES AND (*Al*, *Si*)-ORDERING

Chessboard albite exhibits the same optical features as the secondary albite that replaces primary plagioclase (Tables 6, 8). In albite from volcanic rocks, the extinction angles $\alpha \wedge$ (001) in sections $\perp \gamma$ or in splinters (010) do not always correspond to the value characteristic of pure *Na*-feldspar (20—22°). Quite often this value is smaller (12—16°), despite the fact that the refractive indices indicate an An_0 composition. The chessboard albite replacing microcline in the investigated granitoids shows almost constant values of that angle (20—22°).

The optic axial angle $2V_\alpha$ in the chessboard albite of volcanic rocks is usually 80—93°, which corresponds to high intermediacy index *I. I.* = 60—80 (Fig. 20). However, some of such albite replacing sanidine in trachytes of the Khorai-Sheere massif (Western Mongolia) exhibits a $2V_\alpha$ angle as small as 71°, which indicates a definitely intermediate structural state defined by *I. I.* = 42 (Fig. 20, *point 2*). Similar values of the $2V_\alpha$

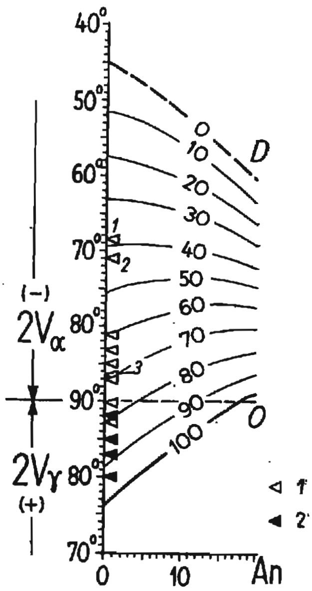

Fig. 20

Variation of optic axial angle and of Slemmon's (1962) intermediacy index (*I.I.*) of the chessboard albites developed in the Sudetic and Khasagtu Khayrkhan Ula volcanic rocks (*1*) and granitoids (*2*)

D — disordered plagioclases (*I.I.* = 0), *O* — ordered plagioclases (*I.I.* = 100); *1*—*3* — albites replacing sanidine phenocrysts in Crowsnest volcanics (*1*, *3*) and in trachyte (*2*) of the Khorai Shire massif, Western Mongolia

angle 68.5—86.6° (*I. I.* = 38—70, Fig. 20, *points 1, 3*), were determined by Crook (1962) in chessboard albite replacing sanidine in pyroclastic rocks (?Cretaceous) from Crowsnest in Alberta, Canada. In granitoid rocks, the albite replacing microcline is characterized by angles $2V_\gamma$ = 80—88° and *I. I.* about 80—95 (Fig. 20, *full triangles*), which are much higher than in the chessboard albite developed from potassium feldspars of volcanic rocks.

Intermediate structural states of the chessboard albite of volcanic rocks have probably been inherited from the intermediate structural states of potassium feldspar. Such an opinion has been advanced by Crook (1962), who has revealed, following optical and X-ray powder results, an intermediate ordering state both in sanidine and in the chessboard albite replacing it. Additional evidence may be sought in the experimental exchange of alkalis in natural feldspars under anhydrous environment, which has been found to cause no change in the structural state (Laves 1951; Wyart & Sabatier 1956a, b, 1961; Goldsmith & Laves 1961; Duffin 1964; Orville 1962, 1963; Manecki 1970).

CHARACTERISTICS OF TWINNING

Chessboard twinning in albite forms a system of delicate, short, irregularly developed lamellae (Pl. 4, Fig. 3; Pl. 5, Figs 1—2; Pl. 6, Figs 1—3). The thickness of the particular lamellae is highly variable and they are frequently wedge-shaped (Pl. 5, Figs 1—2; Pl. 6, Figs 1—2). The chessboard albite of volcanic rocks shows only Albite twins, the lack of Pericline lamellae having been noted also by Callegari & De Pieri (1967). A combination of two sets (*i.e.*, the Albite and Pericline lamellae) exists only in albites which replace microcline in the granitoids under study.

In some cases, the chessboard albite shows relict composition planes of the Baveno, Manebach, and Carlsbad twins inherited after primary potassium feldspar (Fig. 21). These planes are the only traces of twinning structure of the primary feldspars. The Albite- and Pericline-twinned chessboard albite has not inherited that twinning after cross-hatched microclines. In such albites with relict microcline the Albite and Pericline lamellae of microcline are much thinner than those in albite and, besides,

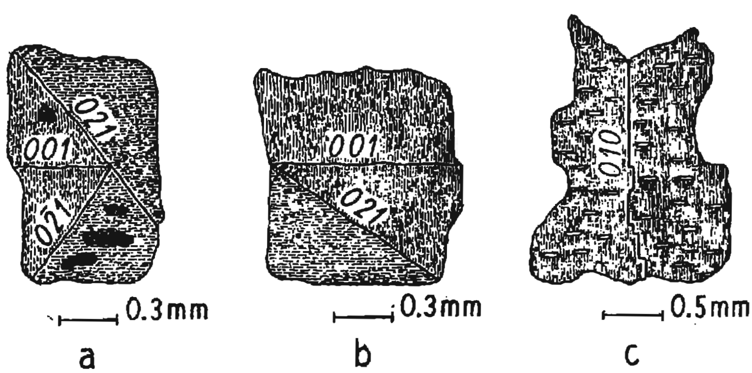

Fig. 21. Relic junctions of the Baveno-, Manebach- and Carlsbad twins preserved in the chessboard albite pseudomorphs of granitoids (*a*, *c*) and volcanites (*b*); orientation of sections $\perp a$

a — combination of Baveno (right and left)-Manebach twins; black patches indicate relics of primary K-feldspar; alkali granite from Bandan Dashiling, Western Mongolia,

b — combination of Baveno-Manebach twins; rhyodacite from the Dzabkhan Trough, Western Mongolia,

c — Carlsbad twin; Izera leucogranite from Kopaniec, Sudetes the orientation of Pericline twins in chessboard albite and microcline is different. These relations are best observed in (001) and (010) sections of albites containing relict microcline.

In the (001) section of such a feldspar, in the albite part only a set of Albite lamellae is visible, whereas the portion of relict microcline reveals a grid of Albite and Pericline twins. In (010) sections, Pericline lamellae of relict microcline are almost perpendicular to (001) cleavage traces, while in the albite part the attitude of *PCP* traces is much more gentle. This is why both sets of twinning lamellae in albite appear in sections $\perp$ [100] (Pl. 6, Fig. 1). The Pericline lamellae in sections $\perp$ [100] show wedge-like forms (Pl. 6, Fig. 1), but their boundaries in sections $\perp$ [010] are so irregular that the measurement of the σ_{PCP} angle is virtually impossible (Pl. 6, Fig. 2). This property, observed in the chessboard albites from the Izera leucogranite, allows one to distinguish between the albite replacing microcline and that developed at the expense of plagioclase. In sections $\perp$ [010], the albite developed at the expense of microcline shows a very irregular *PCP* (Pl. 6, Fig. 2), whereas in that replacing primary plagioclase these planes are very regularly developed (Pl. 3, Figs 2—3).

The primary plagioclase of the Izera leucogranite were recognized by K. Kozłowski (1974) as being of an albite composition. The author's studies of the *PCP* position (σ = 5—10°) have revealed, however, that its primary composition was that of oligoclase-andesine An_{27-37} (Fig. 14, *circles*). Such primary feldspar was transformed into normally twinned albite with inherited twins. Only insignificant parts of the chessboard twins occur in this albite. They form a dense system of fine Albite lamellae that are even more subtle and shorter than the Albite chessboard twins in albite replacing microcline. Such a pattern is also noted within broad Albite lamellae that are sometimes slightly bent due to dynamic deformations of the leucogranite (Pl. 6, Fig. 3). The Pericline twinning of chessboard type is missing in feldspars of that kind. The chessboard twins replace relict Albite twins, but they do not obliterate relict Pericline twins. A section $\sim\perp$ [010] of such a feldspar (Pl. 6, Fig. 4), when rotated on the universal stage some 30—40° around vibration direction β, exhibits a dense system of chessboard lamellae. The σ_{PCP} angle = 10° in that albite corresponds to a composition of An_{27} for the primary plagioclase (Fig. 14, *open circle*).

The question arises, during which stage of plagioclase transformation did the chessboard albite develop in the Izera leucogranite. It might have formed either during the process of albitization of primary plagioclase (oligoclase-andesine), or as a result of alteration of secondary, normally twinned albite. The latter possibility seems to be less probable, as we shall see below.

ORIGIN OF CHESSBOARD TWINS IN ALBITE REPLACING POTASSIUM FELDSPAR AND PRIMARY PLAGIOCLASE

According to criteria set forth by Vance (1961), the chessboard twinning of albite replacing potassium feldspar and primary plagioclase exhibits morphological features of growth twins. It is characterized by variable thickness, which changes either abruptly (Pl. 5, Figs 1—2), or gradually (Pl. 6, Figs 1—2). The growth nature of these twins is also proved by their existence in albite representing various stages of replacement of potassium feldspar. They occur both in small portions that are symptoms of the initial stage of albitization (Pl. 4, Fig. 3), and in albite that has completely replaced potassium feldspar: the inference is that the twins are contemporaneous with the development of albite.

From reference data and the author's own studies, there seem to be three possible causes of the development of chessboard twinning in feldspars:

1. Strains of internal or external nature. The former, according to Callegari & De Pieri (1967), may be connected with the fact that the cell volume of potassium feldspar is greater (sanidine — 803.9 $Å^3$; microcline — 801.9 $Å^3$) than that of the albite developed at its expense (741.1 $Å^3$). External strains, according to Starkey (1959) are connected with stress leading to the development of mechanical twins.

The mechanical nature of chessboard twinning seems improbable in the light of Laves' theory (1952, 1965), which states that mechanical twinning is possible only in plagioclase in which the Si/AlO framework is nearly or exactly topologically monoclinic. In the case of albite, this condition can be fulfilled only by a disordered form. Hence, it would be difficult to ascribe a mechanical origin to chessboard twinning in albite developed at the expense of plagioclase in the Izera leucogranite, as those feldspars are almost completely or completely ordered ($I.I.$ = 90—100; $2V_\gamma$ = 76—91°, *cf.* Fig. 20). Besides, the influence of stresses on the development of chessboard twinning in albite of the studied rocks seems to be unlikely, as the volcanic rocks in general do not show dynamic deformations, and the intensity of deformations of the granitoids is correlated neither with the habit, nor with the quantitative share of chessboard albite.

Contrary to Laves' theory, mechanical twinning is observed in almost pure, considerably ordered albites. Typical deformation twins have been recognized by Capedri (1970) in albites An_{0-5} of intermediacy index $I.I.$ = 70—93 ($2V_z$ = 87—100°, *cf.* Fig. 20), in albitized gabbro, and albitite (Scoltenna Valley, Apennines). Nevertheless, the contradiction between the observations of Capedri and the theory of Laves is most probably only apparent, because deformation twins might have been formed already in primary, more basic, plagioclase. The more anorthite the structure of such a plagioclase contained, the more sensitive it would be to the development of mechanical twins. Postdeformational secondary albite could inherit the mechanical, as well as the growth twins.

It follows from the above considerations that it is possible to make use of mechanical twins as indicators of the secondary origin of albite in rocks in which the primary plagioclase had an ordered structure.

2. According to the present author, the development of chessboard albites may be largely controled by the primary character of albitized feldspars. Such an opinion is based on the observed regularity with which chessboard albite substitutes for potassium feldspar, and only exceptionally for plagioclase. Chessboard albite developed at the expense of primary plagioclase is known exclusively from plutonic

rocks. The primary feldspar of those rocks belongs to the low-temperature series, in which the existence of peristerites is possible. According to the hypothesis put forth by Voll (*in* Brown 1965), the plagioclase transformed to chessboard albite was originally peristerite. The inhomogeneity of peristerite is reflected in the chessboard twinning of albite (Brown 1965).

3. Temperature lower than that at which normally twinned albite develops may be regarded as a third possible cause of origin of the chessboard albite. Evidence may be found in the observed chronological succession of development of albite normally and chessboard twinned. In volcanic rocks, plagioclase is the first to undergo albitization. It is replaced by nonchessboard albite which inherites its twins. In many cases, thoroughly albitized plagioclase coexists with potassium feldspar which is perfectly preserved or only slightly altered. In granitoids, on the other hand, normally twinned albite substituted for primary plagioclase occurs with chessboard albite developed at the expense of potassium feldspar preserved in the form of numerous relicts. This proves that potassium feldspar is more resistant to albitization than primary plagioclase, and the albitization of plagioclase is followed by the development of chessboard albite that replaces potassium feldspar. It may be determined that in a given rock chessboard albite originated later, and probably at temperatures lower than the normally twinned albite.

Small scale development of chessboard albite is known to appear in the course of the low-temperature albitization of plagioclase. In the Izera leucogranite, mainly the normally twinned albite developed at the expense of primary plagioclase (oligoclase-andesine). In some parts, it passes into chessboard albite (Pl. 6, Fig. 3) which seems to be younger than the albite normally twinned.

The above observations suggest that temperature may be the decisive factor controling the kind of twins in albite which replaces primary feldspar. In nature, the development of such albite depends both on the character of replaced feldspar, and on temperatures of their albitization. Differences in ordering state between normally and chessboard twinned albites (Table 10) in volcanic rocks may also be due to differences in tempe-

Table 10

Intermediacy index from the optic axial angle of secondary albites occurring in albitized rocks from the Sudetes, and from the Khasagtu Khayrkhan Ula Mts (Western Mongolia)

No.	Albite varieties	$2V_\alpha$ $\pm 1^\circ$	Intermediacy index I.I.
	Volcanic rocks:		
1	Normally twinned albites after primary plagioclases	$78 - 105^\circ$	55 - 100
2	Chessboard albites after sanidine and orthoclase	$71 - 92.5^\circ$	43 - 80
	Granitoids:		
3	Normally twinned albites after primary plagioclases	$96 - 108^\circ$	87 - 100
4	Chessboard albites after microcline	$92 - 100^\circ$	79 - 93

ratures at which the two kinds of albites originated. The chessboard albite shows a tendency to lesser ordering than the normally twinned albite, and the example of adularias proves that very low temperatures favor the development of feldspar of rather disordered structure.

DISCUSSION ON THE PETROLOGICAL SIGNIFICANCE OF ALBITE

The albitized volcanic rocks (acid and intermediately basic) and granitoids studied by the author contain two kinds of secondary albite $\sim An_0$: albite of normal development of twins, and chessboard albite. Normally twinned albite is a dominant component of these rocks, and is a product of metasomatic albitization of primary plagioclase; chessboard albite originated mainly at the expense of potassium feldspar, and (exceptionally) of acid plagioclase (only in the Izera leucogranite).

NORMALLY TWINNED ALBITE

This variety of secondary albite presents a peculiar kind of pseudomorph that has inherited all morphological details including twinning from the primary plagioclase. In some cases, relicts of primary plagioclase have been preserved, and in others the excess of calcium has been bound in epidote or calcite. The morphological features of twins in these pseudomorphs correspond, according to criteria of Vance (1961), to typical growth twins. In a volcanic plagioclase An_{45}, a peculiar type of Ala-A twinning has been discovered, in which, in analogy with the Pericline law, its composition plane is a rhombic section, but belonging to the [100] zone (Fig. 7).

The occurrence of Pericline twins with the composition plane not parallel to (001) is limited (with but few exceptions) to primary plagioclase (albite-andesine) and to albite developed at its expense (acid igneous rocks). The basic plagioclase (labradorite-bytownite), on the other hand, and albite developed at its expense, is frequently twinned according to Acline-A law, whereas the Pericline twins are almost entirely absent (intermediately basic volcanites). The Acline-A twins have also been encountered in the primary plagioclase (oligoclase-andesine) and in the secondary albite of some acid volcanic rocks. Twinning of [010]/(001) type in plagioclase of intermediate (*Al, Si*)-ordering and of composition $\sim An_{42}$ may belong either to the Acline-A or to Pericline laws, but it is impossible to distinguish them.

The albites $\sim An_0$ of volcanic rocks and granitoids are characterized by the variable position of the *PCP*. The σ angle of that plane in volcanic albite varies from —3° up to 14°, and in the albite of granitoids from 0° to 37°. The position of the *PCP* in relict plagioclase An_{22}—$_{42}$ preserved in secondary albite of volcanic rocks shows that the primary plagioclase at the moment of the development of its Pericline twins had an intermediate and approximately constant (*Al*, *Si*)-ordering state (*V*-curve in Fig. 10). The σ_{PCP} angle of secondary albite from these rocks indicates on the *V*--curve a composition for the primary plagioclase almost identical to that of the relict plagioclase (Fig. 11). On this basis, one may assume that in secondary volcanic albite the σ angle of inherited Pericline composition plane corresponds to the composition of primary plagioclase if an approximately constant intermediate ordering state (defined by curve *V* in Fig. 10) is assumed.

The σ_{PCP} angle of albite An_0 derived from quartz keratophyres of the Sudetes, and of the Virgin Islands (*cf*. Donnelly 1963) shows on the *V*--curve a composition for the primary plagioclase of oligoclase-andesine, very close to that of relict plagioclase in albitized rhyolites and rhyodacites from the Sudetes and the Khasagtu Khayrkhan Ula Mts (Western Mongolia) and in quartz porphyries from Bozen, in the Alps (investigated by Karl, 1954). There is a striking similarity in the composition of primary plagioclase An_{24-35} of the quartz keratophyres from the Virgin Islands, as detected by means of the above method, and that of the plagioclase An_{19-32} partly replaced by albite found by Donnelly (1963). Such close similarities in composition probably are not accidental, but are connected with the generally acid petrographic character of these quartz-porphyry rocks. Oligoclase and andesine are the most characteristic plagioclases in such rocks in unaltered state.

According to data presented by Starkey (1967), the σ angles of rhombic section in the plagioclase of plutonic rocks plot along the *P*-curve (Fig. 10), which roughly represents a constant and nearly maximum (*Al*, *Si*)-ordering state. The σ_{PCP} angle of secondary albite of the metasomatized Sudetic granitoids, when referred to that curve, suggests a composition of primary plagioclase almost identical to that of the plagioclase from unaltered counterparts of the same rocks (Table 5).

The above facts seem convincing enough to suggest a method of determination of the approximate composition of primary plagioclase on the basis of the σ_{PCP} angle of secondary albite, assuming the ordering state described either by the *V*-curve (volcanic and vein rocks) or the *P*--curve (plutonic rocks). Obviously, the feasibility of the method is restricted to nonrecrystallized albite that has preserved details of the twin structure of the primary plagioclase.

The almost invariably secondary origin of rock-forming albite, demonstrated in this paper, does not corroborate the view that the main (Smith 1958, 1962) or only cause (Barth & Thoresen 1965; Barth 1969) of the variable position of the *PCP* in albite An_0 is the structural state, which is controled by the crystallization temperature. According to that view, albite of variable σ_{PCP} value should be regarded as primary, notwithstanding the generally secondary nature of the investigated albite of volcanic and granitoid rocks.

The position of the *PCP* is an important feature, distinguishing secondary from primary albite, particularly in plutonic rocks and hydrothermal veins, as the structural state of primary plagioclase in such environments is almost completely or maximally ordered. At such a structural state, the σ_{PCP} values in primary albite are 30—37°, while lower σ values point to a secondary origin for this mineral. In the granitoids studied by the author, primary albite was found only sporadically: it never forms single grains, but only external parts of grains previously richer in anorthite (Fig. 16*b*, *c*).

The secondary origin of albite An_0 in plutonic rocks is also suggested by mechanical twins. According to Laves (1952, 1965), such twins are impossible in ordered albite, although they are possible in other plagioclases, and the more anorthite the plagioclase contains, the more easily mechanical twins develop. The fact that secondary albite inherits growth twinning from primary plagioclase leads to the supposition that the origin of the mechanical twins sometimes observed in highly ordered albites $\sim An_0$ of plutonic rocks (*e.g.* Capedri 1970) may be the same.

In the light of the above data, the supposition of Laves & Schneider (1956) that the Alpine periclines are pseudomorphs after oligoclase (Table 1, No. 2) seems obvious. In the author's opinion, much previously studied albite crystals is also secondary (*i.e.*, that which exhibit a small σ_{PCP} value, *e.g.*, see Nos 1—6, 10 and 11 in Table 1). Probably also the albite An_8 from Somero in Finland and from Kragerö in Norway (reported by Schmidt 1919)[8] is of secondary origin (Fig. 10, *points marked by "?"*). The dominant influence of (*Al, Si*)-ordering in structure on the σ_{PCP} values $\sim 0°$—22° of the albites in question is hardly probable, as variability of ordering would indicate a considerable fluctuation in temperature attaining high values which, particularly under vein and plutonic conditions seems rather unlikely.

In the volcanic rocks, it is impossible to distinguish between secondary albite $\sim An_0$ and the primary high-temperature form on the basis of the position of the *PCP*, because the σ values in both kinds of albite may be very similar. This follows from experimentally established σ values of rhombic section in artificially disordered albite (Fig. 9), which are very close to σ_{PCP} values (from 6.5° down —3°) of the examined secondary albite of volcanic rocks. However, the present author's studies revealed that the mentioned low values of σ_{PCP} in the albite of volcanic rocks reflect the secondary origin of the feldspar.

The criteria used so far for the identification in volcanic rocks of primary, high-temperature albite $\sim An_0$ as, *e.g.*, the more or less disordered structural state, or the sometimes observed bent albite laths (Donnelly

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[8] The optical properties of albites reported by Schmidt (1919) point to a composition of an almost pure *Na*-feldspar according to diagram of Burri, Parker & Wenk (1967, Table 11).

1963; Velinskij 1968) are illusive, because the same features have been also found in the secondary albite of the volcanic rocks under study (Figs 5 and 20). Besides, the recognition of primary volcanic albite is even more difficult, because of all plagioclase the disordered forms of albite are most readily transformed into ordered forms (Eberhard 1967). The observations of the present author show that primary albite $\sim An_0$ in volcanic rocks should be characterized by σ_{PCP} angle of about 14°. This value has been ascertained only in the external portions of albite pseudomorphs after oligoclase-andesine in the so called Paczyn gneisses that are epimetamorphosed subvolcanic rocks.

CHESSBOARD ALBITE

The chessboard albite of volcanic rocks studied by the author originated at the expense of sanidine and orthoclase, and those of the granitoids originated at the expense of grid-twinned microcline. Only Albite lamellae are developed in the chessboard albite of volcanic rocks, whereas Pericline lamellae are lacking. Both sets of chessboard lamellae (*i.e.*, Albite and Pericline lamellae) occur together only in albite replacing microcline. The boundaries of Pericline twins in sections (010) of such albite are so irregular that a measurement of the σ_{PCP} angle is impossible (Pl. 6, Fig. 2). Such irregularity makes a clear distinction between chessboard albite developed at the expense of microcline, and coexisting secondary albite which is normally twinned and replaces primary plagioclase (Pl. 3, Figs 2—3).

Chessboard twins only on Albite law have been encountered also in albite replacing primary plagioclase (oligoclase-andesine) in the Izera leucogranite (Pl. 6, Fig. 3). The development of this twinning does not obliterate primary Pericline twins, hence it is possible to detect not only the secondary nature of the albite, but also the primary composition of the plagioclase (Pl. 6, Fig. 4).

The chessboard twinning of albite replacing potassium feldspar and plagioclase is characterized by morphological features typical for growth twins. The influence of stress on the development of these twins seems to be improbable, as the volcanic rocks under study do not exhibit dynamic distortion at all, and the degree of dynamic deformation in the granitoids is correlated neither with texture, nor with the proportion of the chessboard albite.

It is the author's supposition that temperature seems to be the decisive factor in the development of chessboard albite. It was lower than during the development of normally twinned albite replacing primary plagioclase in the same igneous rocks. This conclusion is based on the observation that potassium feldspar was evidently more resistant to albitization than primary plagioclase.

(Al, Si)-ORDERING OF SECONDARY ALBITE IN THE LIGHT OF VARIABILITY IN THE OPTIC-AXIAL ANGLE

The values of optic-axial angle $2V_\alpha$ indicate a considerable differentiation of the degree of ordering (expressed by the intermediacy index *I. I.*) in secondary albite developed at the expense of primary plagioclase (normally twinned albite) and of potassium feldspar (chessboard albite) in the studied volcanic rocks and granitoids (Table 10). Both normally twinned and the chessboard albites of volcanic rocks show intermediate (*Al, Si*)-ordering, grading into almost maximally ordered structural states (Figs 5 and 20). Besides, the ordering state of chessboard albite is usually lower than that of normally twinned albite. In granitoids, on the other hand, both albite varieties are much more highly ordered at a relatively small variability range of the intermediacy index *I. I.*, although there is a tendency toward greater ordering in normally twinned albite than in chessboard albite.

Distinct differences in the ordering state of albite of volcanic rocks and granitoids are most probably caused by inheritance of structural states from primary plagioclase and potassium feldspar ("structural memory" of Slemmons 1962).

ALBITIZATION IN CONTINENTAL VOLCANITES, AND REMARKS ON THE CLASSIFICATION OF ALBITIZED ROCKS

The process of metasomatic albitization of feldspars, particularly of plagioclase, is a common phenomenon in igneous rocks. So far, a major rôle has been ascribed to albitization mainly in geosynclinal volcanites (spilites, keratophyres) of the initial stage of the orogenic cycle. It turns out, however, that analogous changes also take place on a regional scale in various products of continental volcanism of subsequent type that appear at the end of the orogenic cycle (Nowakowski 1967, 1969; Eckhardt 1971): for example, huge sequences of albitized Rotliegendes volcanites of the Sudetes and the Fore-Sudetic Monocline (Nowakowski 1967, 1968), of Western Pomerania (Ryka 1968), and the Cambrian volcanites of Western Mongolia (Nowakowski 1969) which represent extensive volcanism in Central Asia (S. Kozłowski 1969). Examples of the Carboniferous (Intra-Sudetic Trough) and Caledonian volcanites (Western Mongolia) clearly show that plagioclase in subvolcanic rocks and in dykes is also subject to strong albitization.

Albitization is certainly one of the most important features of the Rotliegendes volcanism in Europe. Aside from the Sudetes, evidences of albitization are known from the Saar-Nahe area *i.a.* in cuselites (Bambauer 1956, 1960), and the basic volcanites of Rotliegendes occurring in the deep substratum of the northern part of West Germany were subjected to strong spilitization (Drong 1958; Eckhardt 1971). Albitization of plagioclase is also known from quartz porphyries of the same age at Bozen, in the Alps (Karl 1954).

The albitization of plagioclase is a common phenomenon also in granitoid rocks (including pegmatites and aplites), but to a lesser degree than in volcanic rocks (Sudetes, Western Mongolia, Niger).

In the author's opinion, the difficulty in recognizing albite replacement of primary plagioclase is the main cause of underestimation of the great role of albitization in igneous rocks. This is mainly because secondary albite inherits the morphology and twins from primary plagioclase, thus becoming deceptively similar to the latter. Their secondary nature can be revealed only by the position of the pericline composition plane, and sometimes by the relicts of primary plagioclase.

Whenever the secondary origin of albite remains undetected, and such albite has completely replaced the primary plagioclase in an igneous rock, the petrographic character of the intrusion or extrusion based on the present composition of rock is misleading. As a consequence of albitization, the systematic position of such a rock has been changed: albitized volcanic rocks have achieved the composition of alkali rhyolite or alkali trachyte (Fig. 22), and albitized plutonic rocks have attained alkali granite or alkali syenite composition.

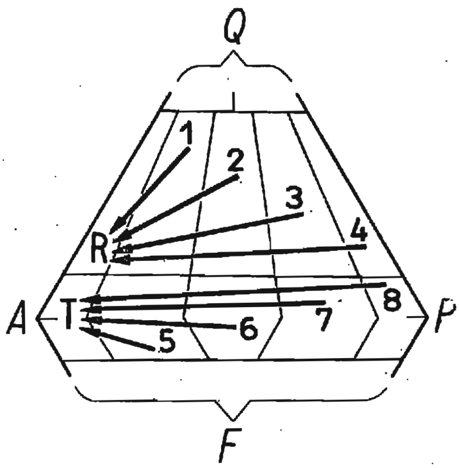

Fig. 22. Change in systematic position of the main volcanic rock types in the case of total plagioclase albitization (classification schema after Smulikowski 1934)

Arrows indicate the direct transition of rocks belonging to the fields *1—8*, into alkali rhyolite (*R*) or alkali trachyte field (*T*)

A — alkali feldspar + plagioclase $<$ An12.5; *Q* — quartz, *P* — plagioclase $>$ An12.5; *F* — feldspathoid

1 — normal rhyolite, *2* — dellenite, *3* — rhyodacite and rhyobasalt, *4* — dacite and quartz basalt, *5* — normal trachyte, *6* — latite and shoshonite, *7* — trachyandesite and trachybasalt, *8* — andesite and basalt

This paper demonstrates that, on the basis of the position of the *PCP* in secondary albite which has replaced primary plagioclase (normally twinned albite), it is feasible to determine the primary composition of the plagioclase. It is also possible to recognize albite developed at the expense of potassium feldspar (chessboard albite). Hence, the detection of the identity of the primary feldspars allows the establishment of the original systematic position of an albitized igneous rock.

The importance of albitization in igneous rocks, in volcanites in particular, in various areas of the world is unquestionable. So far, this process has not been recognized, particularly in rocks where albite has replaced primary plagioclase and has retained its morphology and twins. Such rocks have been regarded as primary, which must have led to a great overestimation of the quantitative role of primary igneous alkali rocks in the earth's crust.

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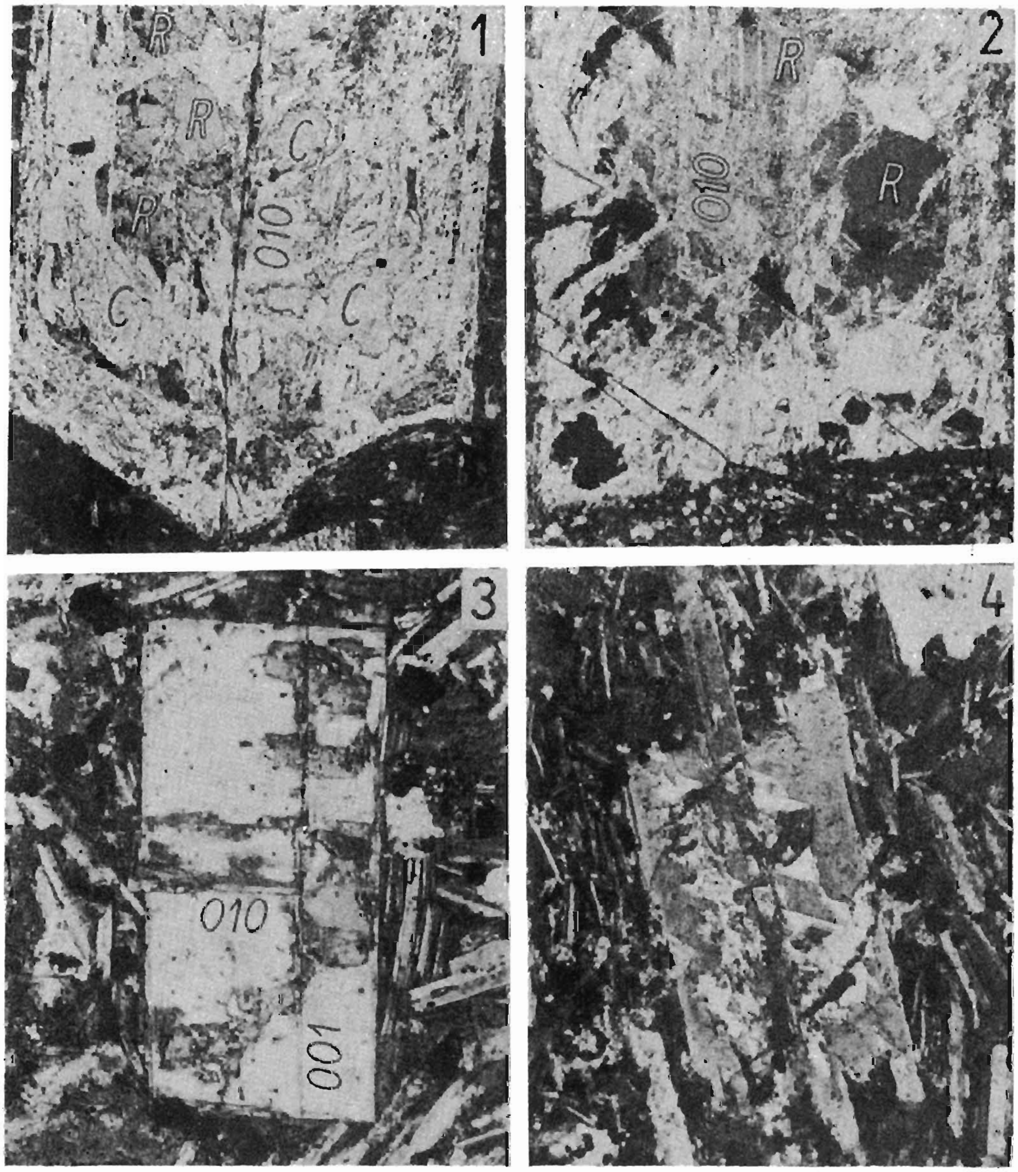
A. NOWAKOWSKI

PETROLOGICZNY ASPEKT ZBLIŹNIACZENIA PERYKLINOWEGO W ALBITACH SKAŁ MAGMOWYCH

(Streszczenie)

Przedmiotem pracy jest studium mikroskopowe wtórnych albitów i towarzyszących im reliktów pierwotnych skaleni (tab. 2—5 oraz pl. 1) w różnych zalbityzowanych skałach wulkanicznych i granitoidach z obszaru Sudetów oraz Gór Chasagtu w Zachodniej Mongolii (fig. 1, 3—4, 15). Stwierdzono, że albity zastępujące pierwotne plagioklazy odznaczają się normalnym wykształceniem lamelek bliźniaczych (fig. 6, 8, 13, 16, 18 oraz pl. 2—3), natomiast albity powstałe kosztem skaleni potasowych (wyjątkowo także kwaśnych plagioklazów) zbliźniaczone są szachownicowo (pl. 4—6). W pierwszym typie zbliźniaczeń rozpoznano naturę reliktową, w drugim zaś wzrostową.

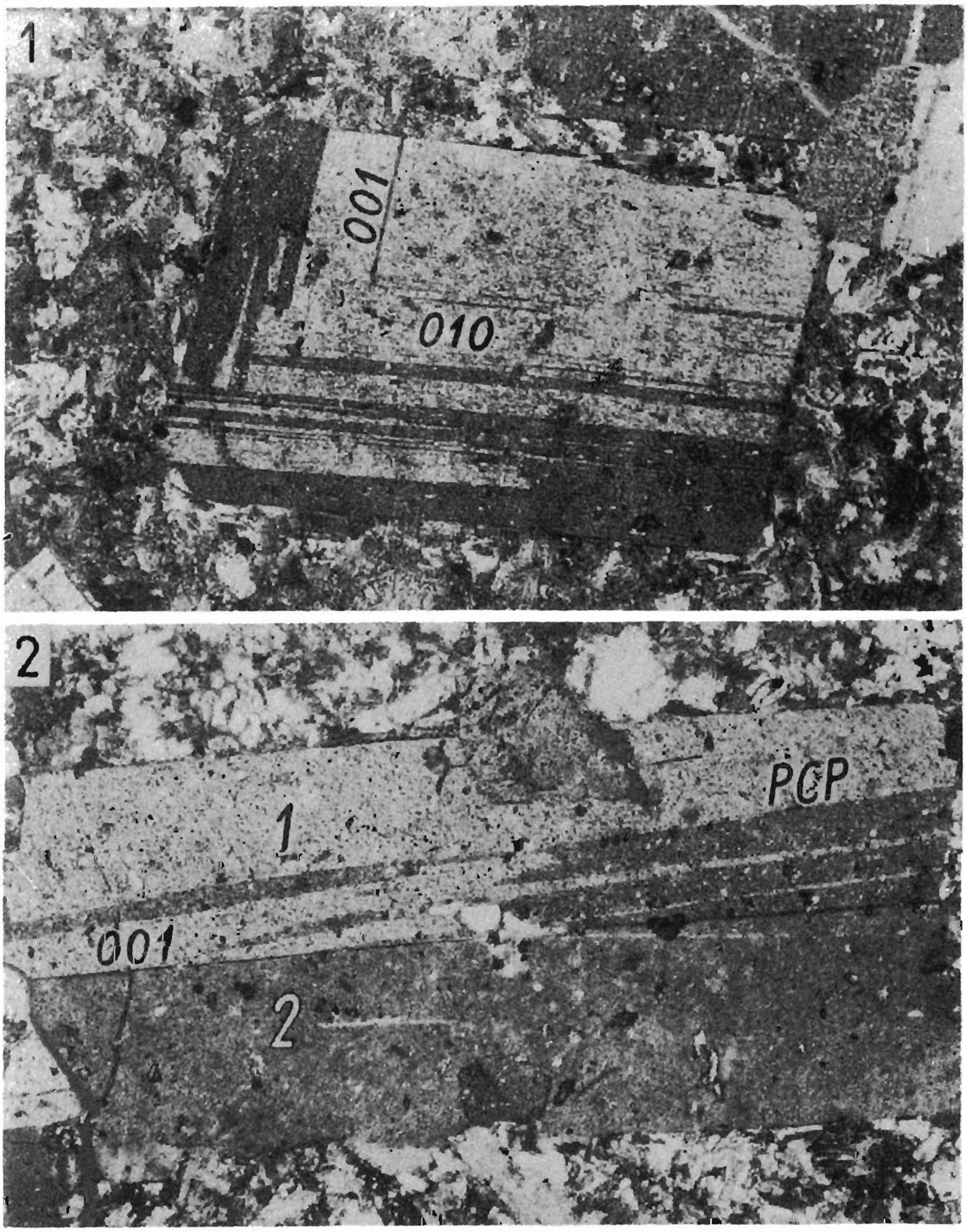
Orientację reliktowej płaszczyzny zrostu zbliźniaczenia peryklinowego (kąt σ) we wtórnych albitach wykorzystano do odtworzenia składu pierwotnych plagioklazów, uwzględniając uprzywilejowany stan uporządkowania atomów Si oraz Al w strukturach plagioklazów wulkanicznych i plutonicznych (fig. 10). Rozpoznanie wtórnej genezy albitów i odtworzenie składu pierwotnych plagioklazów (fig. 11—18) wskazuje, że proces metasomatycznej albityzacji skaleni, zwłaszcza plagioklazów, jest w skałach magmowych daleko bardziej rozpowszechniony, zaś udział pierwotnych skał alkalicznych, zwłaszcza sodowych, w skorupie ziemskiej jest znacznie mniejszy, niż uważano dotychczas.



Symptoms of plagioclase albitization in Sudetic volcanic rocks; nicols crossed

1—2 — Remnants of primary andesine An35 (R) in partly albitized phenocrysts of plagioclase (white parts) twinned according to Carlsbad (Fig. 1 — orientation ⊥ [001]; × 70) and Albite laws (Fig. 2 — orientation 35° to [100]; × 60); *C* — calcite grains in association with chlorite intergrowths (small dark spots); Upper Carboniferous rhyodacite, Inner-Sudetic Trough, Czarny Bór.

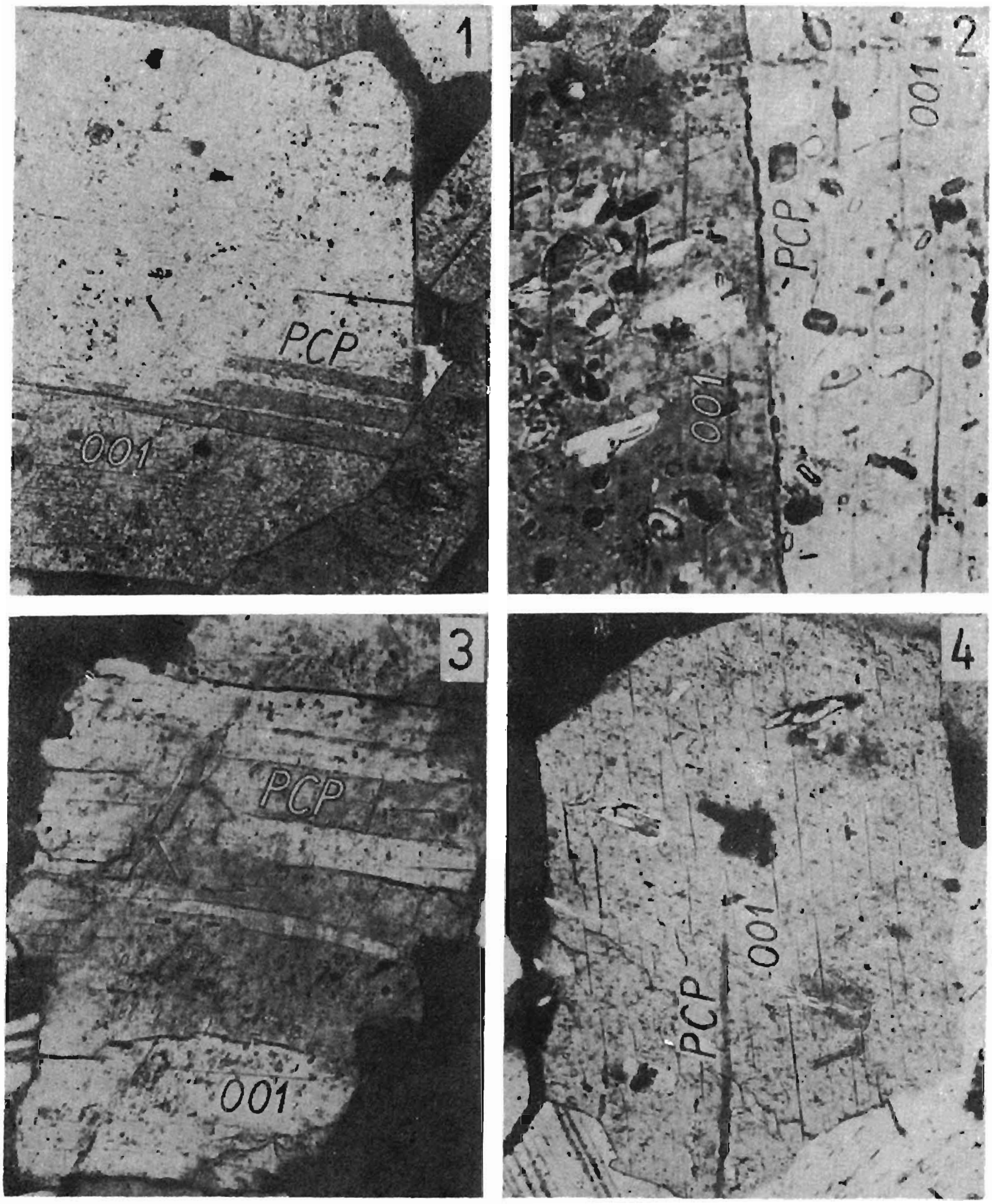
3—4 — Labradorite laths in an initial stage of albitization from the Lower Permian trachybasalt of the Mieszek Hill near Wleń, Kaczawa Mts; *3* — Labradorite An70 (white) and secondary albite parts (dark patches) twinned according to Albite and Pericline or Acline-A? laws (orientation ~ ⊥ [100], × 300); *4* — Simple Acline-A twin of labradorite An73 (grey) with white patches of secondary albite (orientation ⊥ [010]; × 200).



Relic twinnings in albite pseudomorphs after acid plagioclases in altered rhyodacite from the Dzabkhan Depression, Western Mongolia; both pseudomorphs contain small inclusions of epidote grains (black spots); nicols crossed

1 — Albite and Pericline twins in orientation 15° to [100]; × 70.

2 — Ala-A (*1—2*) and Pericline (*PCP*) twins; σ = 4° corresponds to composition An*28* of structurally intermediate plagioclase (orientation ~ ⊥ [010]; × 70).



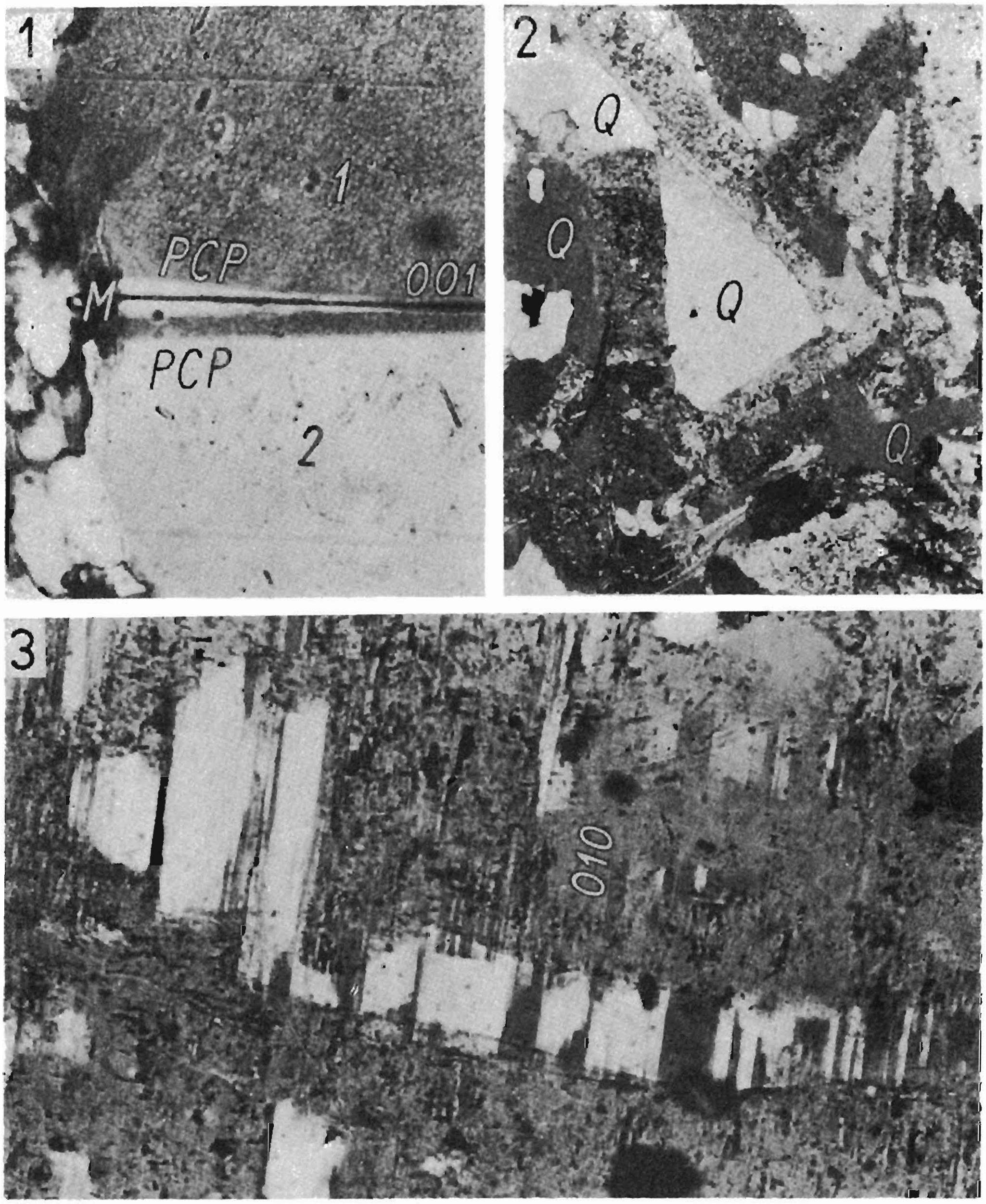
Relic Pericline twins (*PCP*) of secondary albites An*0* replacing primary plagioclases in Sudetic altered rocks (orientation $\sim\ \perp$ [010]; nicols crossed

1 — Triple twins; σ-*PCP* = 3.7° corresponds to composition An*30* of structurally intermediate plagioclase; Lower Permian rhyolite from Bolków, Kaczawa Mts; × 75.

2 — Single twin; σ-*PCP* = 4.6° corresponds to composition An37 of an ordered plagioclase (feldspar contains small inclusions of light mica — white and dark spots); leucogranite from Kotlina, Izera Mts; × 300.

3 — Multiple twins; σ-*PCP* = 5° corresponds to composition An37 of an ordered plagioclase; leucogranite from Proszowa, Izera Mts; × 170.

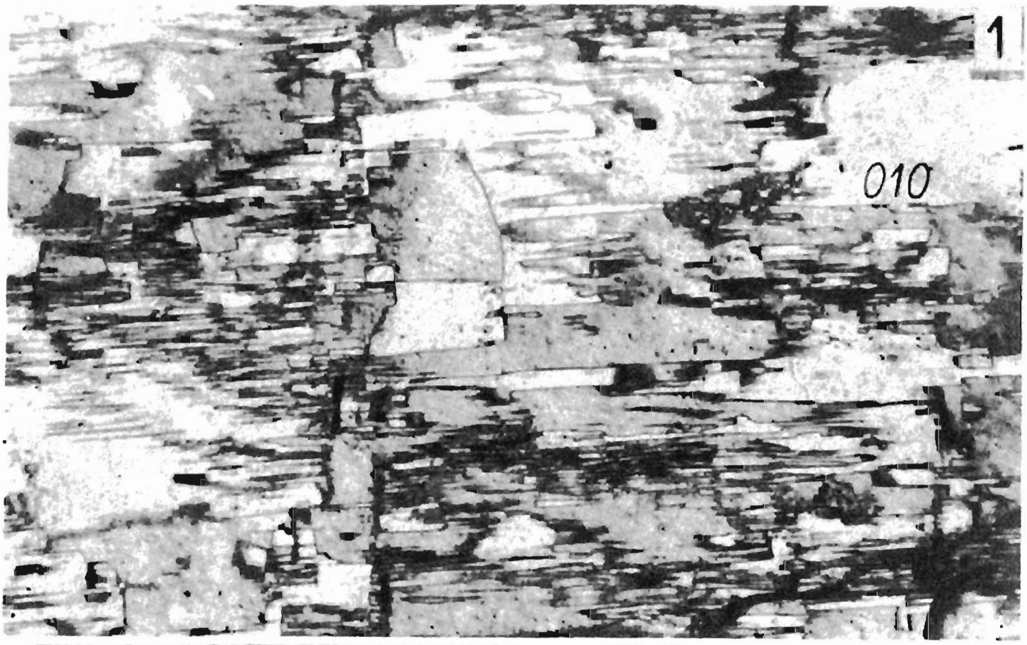
4 — Single twin; σ-*PCP* = 7° corresponds to composition An*21* of structurally intermediate plagioclase; granitic vein in granodiorite from Strzelin; × 130.

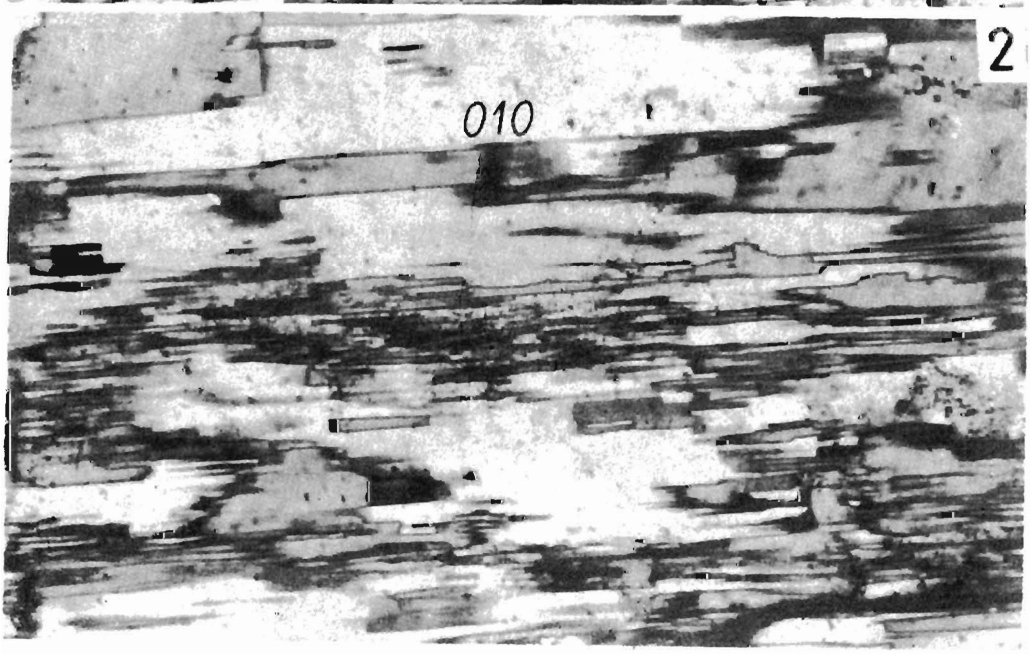


1 — Ala-A (*1—2*), Pericline (*PCP*) and Manebach (*M*) relic twins in albite pseudomorph after acid plagioclase (orientation $\sim \perp$ [010]); σ-*PCP* = 4° corresponds to composition An_{25} of structurally intermediate plagioclase; keratophyre from Sady Górne near Bolków, Kaczawa Mts; nicols crossed, × 300.

2 — Relic dolerite texture of the Paczyn gneiss from Leszczyniec; in albite laths there occur small intergrowths of light mica, chlorite and epidote (dark spots); *Q* — interstitial quartz; nicols crossed, × 50.

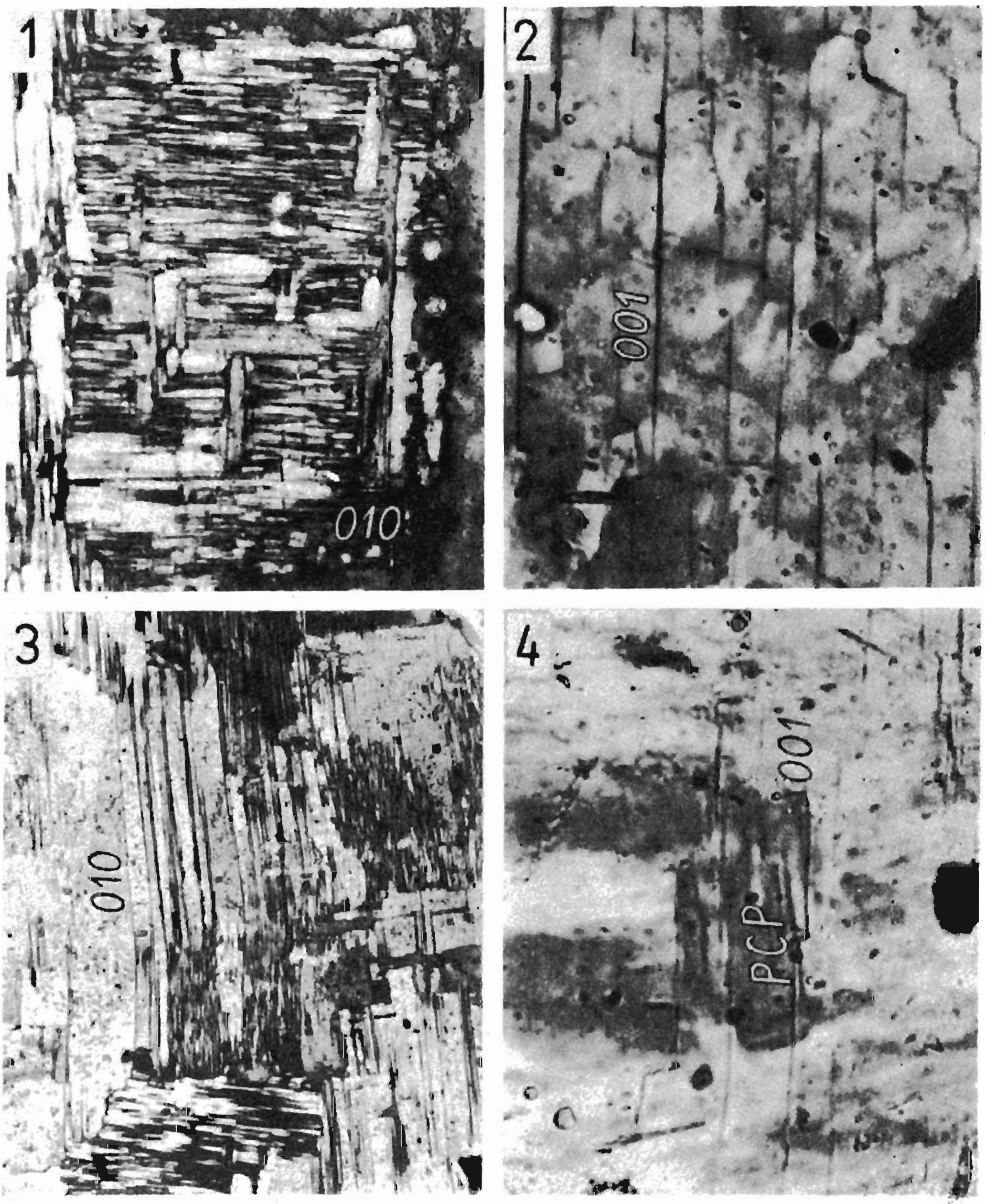
3 — K-feldspar phenocryst in an initial stage of alteration into chessboard albite (orientation $\sim \perp$ [100]); Permian rhyolite, Fore-Sudetic Monocline, borehole Pomorsko (depth 2873.6 m); nicols crossed, × 400.





1 — Pattern of chessboard twinning according to Albite law in albite pseudomorph after K-feldspar phenocryst (orientation ~ ⊥ [100]; Permian rhyolite, Fore-Sudetic Monocline, borehole Jany (depth 2829.8 m); nicols crossed, × 170.

2 — Detailed view of the central part, × 340.



Twinnings of chessboard albites replacing microcline (Figs 1—2) and primary plagioclase grains (Figs 3—4) in the Izera leucogranites; nicols crossed

1 — Albite and Pericline (vertical lamellae) twins in orientation ⊥ [100]; locality Proszowa; × 120.

2 — Irregular boundaries of Pericline twinning (light patches) in orientation ∼ ⊥ [010]; locality Proszowa; × 430.

3 — Chessboard twins according to Albite law partly occupying broad Albite lamellae of a normally twinned albite pseudomorph after acid plagioclase (orientation ∼ ⊥ [100]); locality Świeradów Zdrój, × 90.

4 — Relic Pericline twin (PCP) of chessboard albite replacing acid plagioclase (orientation 20° to [010]); $\alpha = 10°$ corresponds to composition An27 of an ordered plagioclase; locality Proszowa, × 80.