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## PERTHITE FROM TORY HILL, ONTARIO


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TABLE OF CONTENTS



## ABSTRACT


An unusually well-developed perthitic intergrowth of microcline and albite was discovered in pegmatite masses occurring in syenite near Tory Hill, Haliburton County, Ontario. The intergrowth is a composite of several textural varieties. The predominant type is composed of albite spindles developed parallel to the prism directions (110) and $(1\bar{1}0)$ in the microcline. The spindles or blebs along each of these crystallographic directions are arranged *en echelon* and the two sets are superimposed in such a manner as to result in braid-like veins which are approximately parallel to (100). Striking features of this perthite are the uniformity in orientation and size of the blebs, and the high percentage of the albite. The name, *braid perthite*, is introduced as a descriptive term for this textural type.

*En echelon* grouping of albite films (film perthite), as well as of the albite spindles of the braid perthite, is characteristic of the Tory Hill feldspar. This textural feature is also recognized in other perthites, and *en echelon* arrangements may be characteristic of early-formed blebs which by later processes are converted into solid veins or bands. In the Tory Hill perthite, vein or band perthite and patch perthite have been developed from the braid type by replacement. The feldspar components calculated from the chemical analysis of the Tory Hill feldspar are (weight percentages) Ca-f, 0.1; Na-f, 57.7; K-f, 42.2.

The crystallographic directions developed in the Tory Hill perthite are similar to those found in other perthites. It is believed that these directions are related to, and basically controlled by, the atomic structures of the interlaminated feldspars. Similarities between the Tory Hill feldspar and Ceylon moonstone are noted, and the origin of these perthitic feldspars may have points in common. Exsolution and replacement probably accompanied by recrystallization are the processes favored to explain the origin of the feldspar.

## INTRODUCTION

In an investigation[1] of the igneous rocks of the Tory Hill stock in Haliburton County, Ontario, an unusual perthite was encountered. Striking features of this intergrowth are the uniformity in orientation and size of the albite blebs or spindles, and the unusually high proportion of this feldspar. Gradations from this regular intergrowth into less regular patterns are found and are believed to be significant, but the degree of perfection attained in the development of some of the Tory Hill perthite affords an example of regularity equal to, if not surpassing, any illustration in the literature.

Textural characteristics are significant factors in the theories suggested for the origin of perthites. For this reason, the first part of this paper is devoted to a rather detailed description of the Tory Hill perthite. A consideration of the textural features of this perthite and of the similarity of these features to those described by other writers suggests that, fundamentally, perthitic intergrowths are governed by the atomic structures of the component feldspars. This view is elaborated in the second portion of the paper.

## TORY HILL STOCK

Tory Hill stock lies 20 miles southeast of Haliburton, Ontario. The general field relationships as mapped by Adams and Barlow,[2] are shown in Fig. 1. Nepheline syenite forms the outer border of the stock enclosing syenites. The syenites are alkalic and are characterized by soda-rich pyroxenes and amphiboles. Abrupt changes in mineralogical composition are common and result in transitions within short distances from rocks composed chiefly of feldspar to rocks made up largely of ferromagnesian

[1] Kinser, J. H., A petrographic study of the Tory Hill stock, Haliburton County, Ontario: *Master of Science Thesis, University of Minnesota*, **1937**.

[2] Adams, F. D., and Barlow, A. E., Geology of the Haliburton and Bancroft areas: *Geol. Surv. Can., Memoir* **6**, 1910.

minerals. The feldspars are orthoclase, microcline and albite-oligoclase. Microcline-perthites are abundant and commonly form the major por-

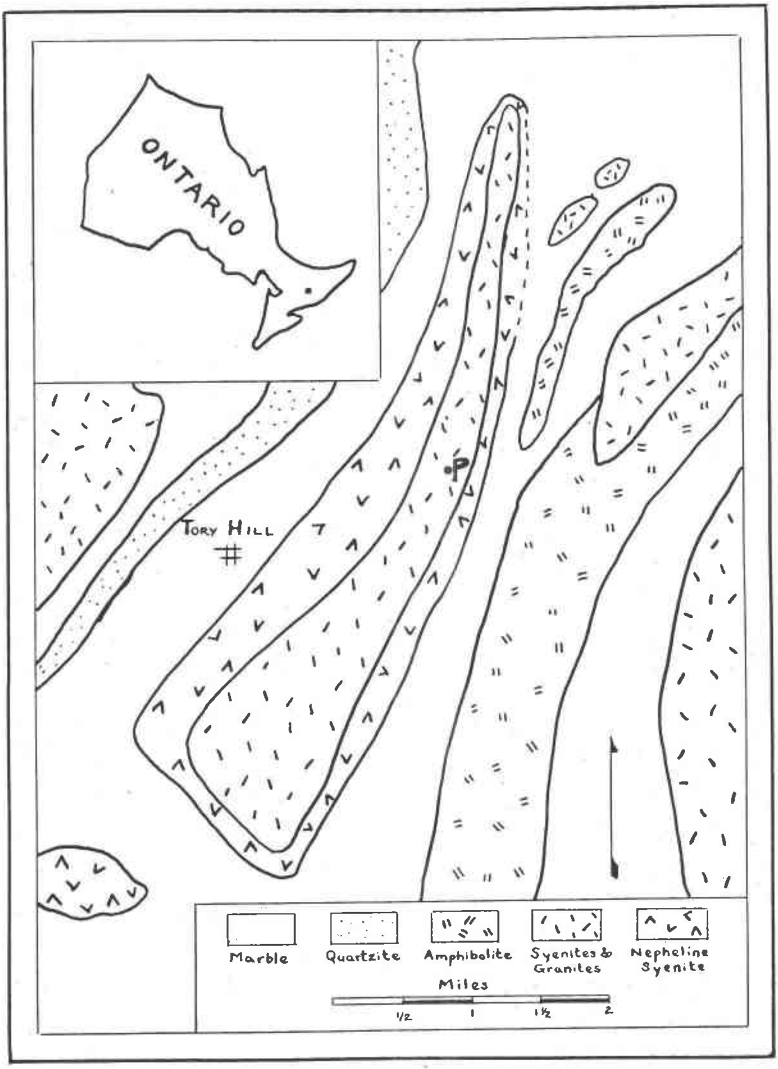



FIG. 1. Map of the Tory Hill area. Geology by Adams and Barlow. Location of perthite at point P.

tion of the feldspar content (Fig. 2; Plate II–E). Sphene is the chief accessory. Quartz was not observed in the thin sections studied.

Texturally, the syenites are coarse granular rocks usually somewhat trachitoid. The ferromagnesian minerals are stubby and show no marked tendency toward parallel alignment, but they do occur in more or less parallel bands which give the rocks a streaked appearance. Abrupt changes in texture, as well as in composition, are characteristic of the central portion of the stock, and pegmatitic masses are abundant.

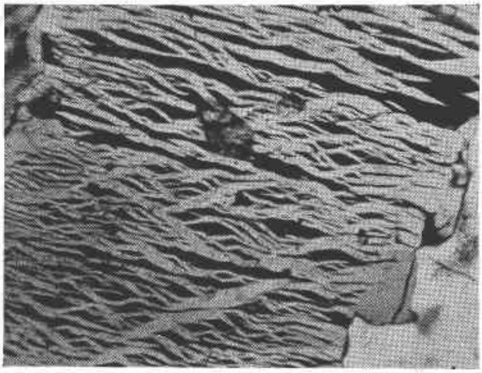


FIG. 2. Perthite from coarse-grained syenite, Tory Hill stock. Microcline, dark; albite, light. Crossed nicols. ×47. This regular intergrowth with exceptionally high albite content is regarded to have been formed, at least in part, by replacement (albitization).

The most notable feature of the pegmatites is their great irregularity. Some appear to be dikes; others, more nearly segregations. At the borders of the pegmatitic masses, black augite crystals about one inch thick stand out in contrast with the light colored country rock. Augite, feldspar, quartz, calcite and pyrrhotite are the abundant minerals in the pegmatites, and in large miarolitic cavities crystals of augite, feldspar and quartz are found. The augite and the feldspar show good crystal forms, but the quartz crystals are corroded.

## PERTHITE

Most of the feldspar in the pegmatites is pale olive-green. This feldspar is fresh and glassy, and thin sections show it to be a perthitic intergrowth of microcline and albite.

### TEXTURAL FEATURES

The perthite was studied in thin sections prepared from the basal (001) and brachy (010) cleavage fragments. The appearance of the intergrowth is quite different on the two pinacoids.

*Braid Perthite*

In sections parallel to (001), microcline, the potassic feldspar component of the perthite, is twinned in accordance with the albite and pericline laws and shows fine to coarse grating structure between crossed nicols. The albite is in braid-like veins which are approximately parallel to (100). The braids are composed of two superimposed *en echelon* groups of albite spindles or blebs oriented parallel to the unit prism directions (110) and $(1\bar{1}0)$. Polysynthetic twinning is not conspicuous in the albite spindles composing the braid, but the type of twinning described by Rogers[3] in the "peculiar" perthite from Port Henry, New York, is developed. The albite spindles parallel to (110) are in the twinning position (albite twinning) with respect to those parallel to $(1\bar{1}0)$, Plate I-A, II-A.

In sections parallel to (010), the albite appears as numerous lens-shaped veins which cut the trace of the basal cleavage at an angle of about 65°. Their elongation, therefore, is parallel to the vertical or *c* axis.

From measurements made on several thin sections, the composition of the braid perthite was estimated (Kinser) as 58 per cent albite and 42 per cent microcline, by volume. The regularity of the intergrowth in sections parallel to (001) is striking, and the pattern is sufficiently distinctive to warrant the name *braid* perthite which is here introduced as a descriptive term.

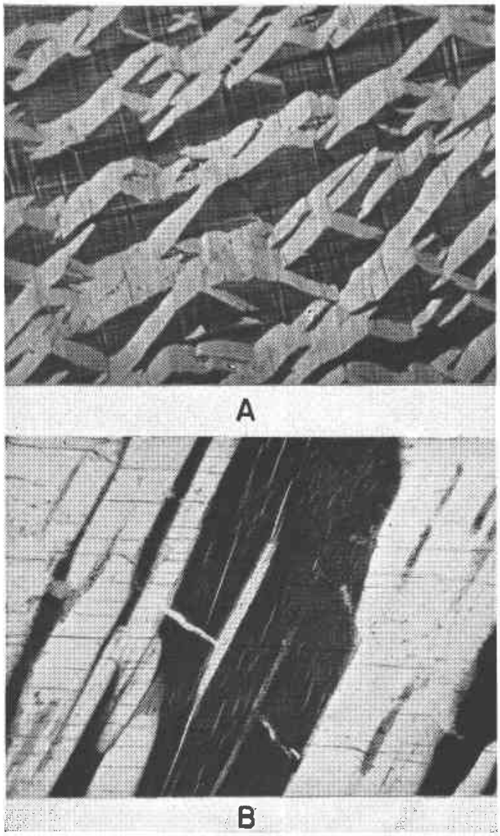
*Film Perthite*

In sections parallel to (001), small stringers or films of albite occur in the microcline. These rarely exceed 0.1 mm. in length and 0.004 mm. in width. The films trend parallel to the general direction of the braids and are parallel to (100). In sections parallel to (010), the films of albite are clearly seen and are differentiated from the vein albite not only by their smaller size but also by their different orientation. The direction of elongation of the films intersects the trace of the (001) cleavage at an angle of about 74°. Thus the films are parallel to a hemidome. This direction is typical of film perthite. Miller indices ranging from $(\bar{6}01)$ to $(\bar{8}01)$ have been assigned to the plane by various investigators. Spencer[4] gives the indices $(13.0.\bar{2})$ and refers to the plane as the perthite or schiller plane. He suggests that the different indices obtained indicate that the orientation of the plane varies with the composition of the feldspar. The schiller plane is undoubtedly the murchisonite parting of some writers.

[3] Rogers, A. F., Observations on the feldspars: *Jour. Geol.*, **21,** 202–203 (1913).

[4] Spencer, E., A contribution to the study of moonstone from Ceylon and other areas and of the stability-relations of the alkali-felspars: *Mineral Mag.*, **22,** 309 (1930).

PLATE I




Tory Hill perthite.
(Crossed nicols. ×66)

A—Section parallel to (001). Braid perthite. The film perthite is obscured by the cross-hatching in the microcline.

B—Section parallel to (010). Microcline, dark; albite, light. Details in the large microcline vein: (1) *en echelon* arrangement of the minute albite films results in groups of films which are parallel to the direction of vein development; (2) a faintly visible vein of sodic feldspar, "phantom" perthite (lower central portion of large microcline vein), contains well-developed albite films suggesting that the *en echelon* groups may be a controlling factor in the development of the vein perthite.

A study of the film perthite under high magnifications shows that the albite films or strings are commonly arranged *en echelon* (Plate I-B). The groups thus resulting trend parallel to the direction of the larger albite veins, suggesting a relationship between the film and vein perthite. This view is further supported by the presence of well-developed *en echelon* groups of albite films within "phantom" veins of sodic feldspar. These veins are not clearly seen in transmitted light, but become visible between crossed nicols.

### *Vein Perthite*

In certain thin sections prepared from the Tory Hill perthite parallel to (001) a transition from braid perthite to ordinary vein or band perthite is noted. These veins are formed by replacement of the microcline in the re-entrant angles formed by the intersection of the albite spindles making up the braid. The veins are parallel to (100) and for this reason cannot be distinguished from the braids in sections parallel to (010). Polysynthetic twinning is well developed in the albite (Plate II-C).

### *Patch Perthite*

By further replacement of microcline by albite, braid and vein perthite grade into typical patch perthite (Plate II-D). The contacts between the microcline and the albite are irregular and islands of microcline of irregular shapes are present in the albite. The twinning lamellae in the albite are sharply defined but are not continuous, a peculiarity of albite in this type of perthite (chess-board albite).

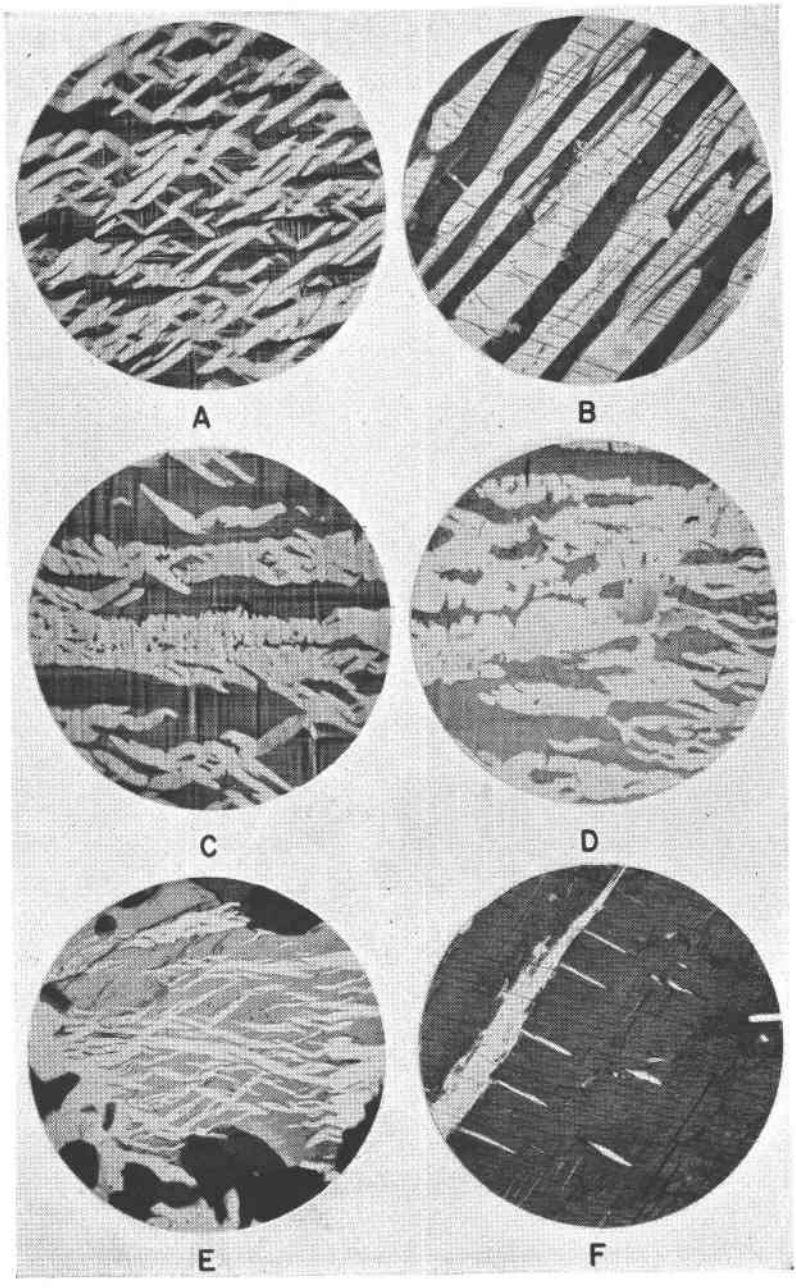
## Crystallographic Relationships

In the twinned albite the composition face is parallel to the trace of the (010) cleavage of the microcline, as seen in sections parallel to (001) The twinning, the cleavage traces, and the vibration directions X and Z with relation to the crystallographic directions in the microcline and in the albite show beyond a doubt that the two minerals have the same crystallographic orientation. This relationship between the component feldspars of the Tory Hill perthite is noted in each of the textural varieties.

## Optical Data

The results of optical study of the feldspar in immersion media and in thin section are presented in Table 1. The data indicate that the microcline and the albite are relatively pure.

Plate II



Textural varieties.

A—Tory Hill perthite. Section parallel to (001). Regular development of braid perthite. The *a* axis is vertical. Crossed nicols. ×32

B—Tory Hill perthite. Section parallel to (010). Crossed nicols. ×32

C—Tory Hill perthite. Section parallel to (001), showing transition from the braid perthite to vein or band perthite. Crossed nicols ×32.

D—Tory Hill perthite. Section parallel to (001), showing transition to patch perthite. Crossed nicols ×32.

E—Microcline-perthite in syenite from Tory Hill stock. Microcline, dark; albite, light. Crossed nicols × 32.

F—Microcline-perthite from granite pegmatite, Granite Mountain, Texas. Section parallel to (010). Crossed nicols. ×64. Poikilitic albite, vein perthite, film perthite, and an unnamed variety in which the blebs make an angle of about 12° with the trace of (001).

TABLE 1. OPTICAL CONSTANTS OF FELDSPARS IN TORY HILL PERTHITE

| | Albite | Microcline |
|---|---|---|
| INDICES: | | |
| Alpha | 1.526 | 1.517 |
| Beta | | 1.522 |
| Gamma | 1.537 | 1.524 |
| EXTINCTION ANGLES: | | |
| On (010) | 19° | 5° |
| On (001) | 4° | 17° |

## CHEMICAL DATA

A chemical analysis of the perthite was made in the Rock Analysis Laboratory of the University of Minnesota and is given in Table 2. An analysis by Warren[5] of perthite from the type locality, Perth, Ontario, is also included in the table. The small lime content of the Tory Hill feldspar is noteworthy and supports the optical data. The components calculated from the analysis are Ca-f and Ba-f, 0.1; Na-f, 57.7; and K-f, 42.2.

TABLE 2. CHEMICAL ANALYSES

| | 1 | 2 |
|---|---|---|
| $SiO_2$ | 66.56 | 66.50 |
| $Al_2O_3$ | 19.04 | 18.40 |
| $Fe_2O_3$ | 0.41 | 1.05 |
| FeO | 0.18 | |
| MnO | | tr. |
| MgO | 0.00 | 0.07 |
| CaO | 0.01 | 0.30 |
| BaO | 0.02 | |
| $Na_2O$ | 6.77 | 5.40 |
| $K_2O$ | 7.09 | 8.77 |
| $H_2O+$ | 0.10 | 0.20 |
| $H_2O-$ | 0.02 | |
| | 100.20 | 100.69 |
| Sp. Gr. | 2.593* | 2.597 |
| Ca-f, Ba-f | 0.1 | 1.5 |
| Na-f | 57.7 | 46.2 |
| K-f | 42.2 | 52.3 |

* 28°/4°.

1—Perthite from Tory Hill stock, S. S. Goldich, *analyst.*

2—Perthite from Perth, Ontario, C. H. Warren, *analyst. Proc. Am. Acad. Arts and Sci.,* **51,** 139 (1915).

[5] Warren, C. H., A quantitative study of certain perthitic feldspars: *Proc. Am. Acad. Arts and Sci.,* **51,** 139 (1915).

## Impurities

Very small amounts of minerals other than the feldspars are present in the Tory Hill perthite. A few thin bands of an undetermined green mineral are oriented with their long dimension parallel to (010). In sections parallel to (010), small narrow plates of a colorless mineral occur along the (001) cleavage cracks in the albite, but are essentially lacking in the microcline. This mineral shows strong birefringence and a marked change in relief on rotation of the stage. It is probably muscovite and appears to be oriented in the albite so that the basal pinacoids of the two minerals coincide.

## COMPARISON OF TORY HILL INTERGROWTH WITH OTHER PERTHITES

The Tory Hill feldspar is a composite of several textural varieties exhibiting the general characteristics of perthites from other localities.

### Perth, Ontario, Intergrowth

Rogers[6] called attention to the tendency of the albite blebs, in sections parallel to (001), to coalesce in such a manner as to practically form solid plates along directions parallel to (110). Dittler and Köhler[7] noted the presence of albite films in this perthite. They state that the direction of development is parallel to the murchisonite parting, making an angle of about 74° with the trace of (001) in sections parallel to (010). Thus, the directions developed in the Tory Hill perthite are found in the intergrowth from the type locality.

### Ambalangoda Moonstone

Spencer[8] found two types of perthitic structures in the moonstone from a weathered pegmatite near Ambalangoda, Ceylon,—a fine regular variety designated (or,ab) microperthite or cryptoperthite, and a coarser (Or,Ab) "shadow" or "lattice" perthite. In sections parallel to (001) the lamellae of the fine (or,ab) microperthite are parallel, for the most part, to the trace of (100), but also branch off in directions corresponding to (110) and (320). On (010) the lamellae (0.05 mm. in length and from 0.0005 to 0.001 mm. in thickness) make an angle of about 73° with the basal cleavage. According to Spencer the plane of (or,ab) microperthite development is the perthite plane, or the plane of schiller with the Miller indices $(13.0.\bar{2})$. The (Or,Ab) "shadow" perthite was so named

[6] *Op. cit.*, p. 203.

[7] Dittler and Köhler, A., Zur Frage der Entmischbarkeit der Kali-Natronfeldspäte und über das Verhalten des Mikroklins bei hohen Temperaturen: *Tscherm. Min. Petr. Mitt.*, **38**, 243 (1925).

[8] *Mineral. Mag.*, **22**, 297 (1930).

because it is clearly visible only between crossed nicols. The directions developed in this perthite are not well defined, but are said to be mainly along the planes (110) and (320).

Spencer has called attention to the similarity of Rogers' "peculiar" perthite and the Ceylon moonstones. He pointed out that the "principal plane of perthite separation is in both cases the unit prism instead of the usual perthite plane."

## Granite Mountain, Texas, Perthite

A microcline-perthite from a granite pegmatite at Granite Mountain, Texas, will serve to illustrate certain textural characteristics of perthites. In Figure F of Plate II, taken of a section parallel to (010), albite is shown in four distinct relations.

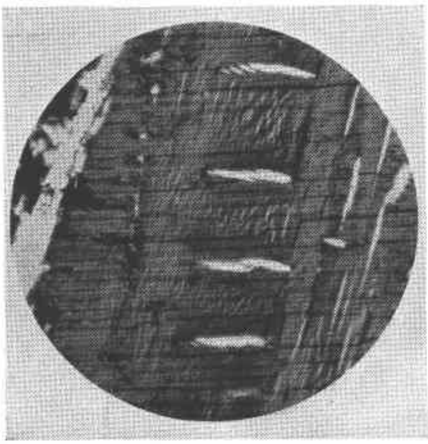


Fig. 3. Microcline-perthite from a granite pegmatite, Granite Mountain, Texas. Section parallel to (010). Crossed nicols. × 82. Film and vein perthite, together with a third type in which small blebs making an angle with (001), form *en echelon* groups. The blebs tend to flatten out in a direction parallel to the trace of the basal cleavage, which is the direction taken by the groups. An absence of albite films in the immediate areas of this type of perthite is conspicuous.

(1) Poikilitic albite, crystals of random orientation are included in the microcline-perthite.

(2) Strings or films of albite with the usual orientation make an angle of about 74° with the trace of the basal cleavage which can be seen as many parallel cracks inclined slightly from a horizontal position in the photomicrograph. A second set of cracks not nearly as well developed as those forming the trace of the basal cleavage, are parallel to the direction of film development and probably represent the so-called murchisonite parting.

(3) Veins of albite, irregular in size and shape, are mainly parallel to the *c* axis and intersect the basal cleavage at an angle of about 66°.

(4) Albite spindles measuring about 0.1 mm. in length and being distinctly larger than the albite films, appear to be related to the direction (001), but actually the direction of the blebs intersects the trace of (001) at an angle of about 12°. Although rare and as yet unnamed, this type of albite development is probably deserving of the rank of a textural variety. Warren[9] has described a perthite from Westfield, Massachusetts, in which small lamellae of albite make an angle of about 12° with the basal cleavage of the microcline in sections parallel to (010).

Figure 3 is a photomicrograph of a section of the Texas perthite parallel to (010) which also shows the film and vein perthite, but of particular interest is the development of the albite blebs related to (001). It is significant that the blebs are *en echelon*, the individual blebs intersecting the trace of the basal cleavage, but the group as a whole is essentially parallel to (001).

## ORIGIN OF PERTHITES

It is noteworthy that each of the prominent crystallographic directions developed in perthitic intergrowths appears to be parallel to a plane of parting or of cleavage in the feldspars. It is not surprising that attempts to explain the orientation of the blebs by many writers have been based upon a correlation of perthite directions with planes of weakness in the feldspars. Such a relationship exists, but the fundamental significance of this relationship has but recently been appreciated.

### Contraction Cracks

The origin of perthites, it has been held, is connected in some manner with the phenomenon of contraction. Dittler and Köhler[10] found that the determined molecular volume of anorthoclase is about $\frac{1}{2}$ per cent greater than the volume calculated on the basis of the feldspar components contained. They suggested that the unmixing of anorthoclase to form perthite is related to contraction. Lehmann[11] has suggested that perthites are formed in connection with contraction cracks. He claimed that by chilling feldspars in water, contraction cracks are developed more abundantly parallel to (100) and parallel to the prism faces (110)

[9] *Op. cit.*, p. 131.

[10] *Op. cit.*, p. 260.

[11] Lehmann, J., Über die Mikroklin- und Perthitstructur der Kalifeldspäthe und deren Abhängigkeit von äusseren, z. Th. mechanischen Einflüssen: *Jahresber. Schles. Ges. vaterl. Kultur*, **63**, 92–100 (1895); **64**, 119 (1896).

and ($1\bar{1}0$), than to the better cleavages (001) and (010). Brøgger[12] in his investigations of the perthites and cryptoperthites of Norway, suggested that these perthites were formed in connection with secondary planes of parting parallel to (100) and parallel to ($\bar{8}01$) (the murchisonite parting). Andersen[13] has developed an elaborate contraction-crack theory and regards such cracks as the controlling factor in the development of vein perthite, and possible also in film perthite. His view is that cracks should develop most prominently in a plane perpendicular to (010) and making an angle of about 70° with (001). This direction is not far removed from the plane of schiller, or from the murchisonite parting.

The openings made available along cracks, which may indeed be contraction cracks, are no doubt of importance in the development of certain perthitic feldspars, but there is much evidence suggesting that there is a more fundamental control in the atomic structures of the interlaminated feldspars.

## Structural Control

A basic structural control in the development of perthites not only affords a logical explanation for the preferential or selective directional development, but also presents an explanation for the observed relationship between the perthite directions and planes of parting and cleavage, which similarly are dependent upon the crystal structure of the feldspars.

### *X-ray Data*

Warren[14] should probably be given credit for anticipating a structural explanation for perthitic feldspars. Taylor[15] has made a definite contribution along this line. In applying data obtained in an *x*-ray investigation of sanidine and albite, Taylor points out that the *a* axes are quite different in the two crystals (8.45 Å in sanidine, 8.14 Å in albite), but the *b* and *c* axes are remarkably similar (12.90 Å and 7.15 Å, respectively in sanidine, and 12.86 Å and 7.17 Å in albite). A tetrahedron framework continuous throughout the lamellae of perthites and cryptoperthites is visualized. Greater and lesser extensions of the chains in the regions of potassic and of sodic feldspar result in the lamellae which appear optically as the two components of the perthite. Taylor is adverse to further speculation on the basis of the data now available.

[12] Brøgger, W. C., Die Mineralien der Syenitpegmatitgänge der Südnorwegischen Augit- und Nephelinsyenite: *Zeits. Kryst.*, **16,** 521–564 (1890).

[13] Andersen, O., The genesis of some types of feldspar from granite pegmatites: *Norsk. Geol. Tidsskrift*, **10,** 116–209 (1928).

[14] *Op. cit.*, p. 149.

[15] Taylor, W. H., Darbyshire, J. A., and Strunz, H., An *x*-ray investigation of the felspars: *Zeits. Krist.*, **87,** 464–498 (1934).

It has been noted, however, that the important crystallographic directions developed in perthitic intergrowths are parallel to directions of cleavage or of parting. The good cleavage in sanidine takes place through the weak potassium-oxygen bonds. The positions of the potassium atoms in the structure are in themselves inadequate in explaining

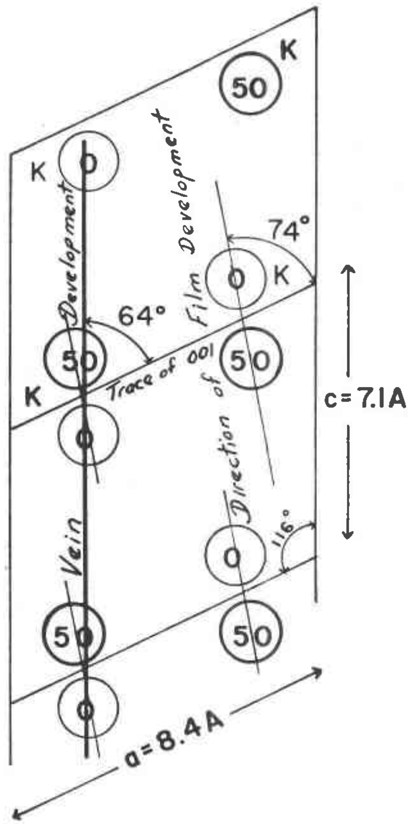



FIG. 4. Relations of film and vein perthite developments to the positions of potassium atoms in sanidine projected on (010). The projection is only approximate and was adapted from Fig. 130, Bragg's *Atomic Structure of Minerals*, p. 235.

perthite orientations. The plane (001), for instance, appears to be of secondary importance. Nevertheless, some clue to the development of film perthite and of the possible relationship between albite films and albite veins may possibly be seen in the positions of the potassium atoms. In Fig. 4 the directions of film and vein developments have been superimposed upon a projection of potassium atoms on (010) for sanidine. A detailed structural analysis of the perthite directions or planes is needed.

*Overgrowths*

Royer,[16] Frondel and Ashby,[17] and Pabst[18] have demonstrated that there is a structural explanation for overgrowths as well as for intergrowths of certain minerals. Structurally similar planes are shared, and these planes determine the orientation.

Miers and Bowman[19] describe and figure an overgrowth of albite crystals on orthoclase. The albite crystals are shown in parallel arrangement on the prism faces of the potash feldspar, and it is stated that the prism zones coincide and that the faces (010), (110), and $(1\bar{1}0)$ are approximately parallel to each other.

*Optical Continuity*

In support of his hypothesis that vein perthite in granite pegmatites is formed by the simultaneous crystallization of the albite and microcline, Spencer[20] writes:

> "In most specimens the "vein" perthite is in optical continuity with the microcline, i.e., the albite-twin lamellae of the perthite lie parallel to those of the microcline. One would expect this to be the case if crystallization of the microcline and perthite had been simultaneous, but not necessarily so if the albite were of later infiltration origin."

One of the features of perthites observed by the writers which was considered worthy of special attention and which is best explained in terms of structural control, is that in perthites of different modes of origin, the sodic and potassic feldspars are in parallel crystallographic orientation, or as Spencer terms it, in optical continuity. It may be that the writers' observations are too limited in this respect, but in the Tory Hill feldspar several textural varieties are recognized and in each the albite is in parallel crystallographic orientation with the microcline, just as it has been found to be in vein and patch perthites from granite pegmatites.

## Processes

In extending the idea of a basic atomic structural control in the development of perthitic intergrowths, the writers contend that the mode of origin influences the rigidity of control, thus giving rise to the textural

[16] Royer, M. L., Recherches expérimentales sur l'épitaxie ou orientation mutuelle de cristaux d'espèces différentes: *Bull. Soc. Fran. Min.*, **51**, 7–151 (1928).

[17] Frondel, C., and Ashby, G. E., Oriented inclusions of magnetite and hematite in muscovite: *Am. Mineral.*, **22**, 104–121 (1937).

[18] Pabst, A., Orientation of bixbyite on topaz: *Am. Mineral.*, **23**, 342–347 (1938).

[19] Miers, H. A., *Mineralogy*, 2nd Ed., revised by H. L. Bowman, pp. 266, 522, Macmillan and Co., Ltd., *London*, **1929.**

[20] Spencer, E., The potash-soda-felspars. Part II. Some applications to petrogenesis: *Mineral. Mag.*, **25**, 107 (1938).

varieties which have been recognized. That perthites are of different origins is well recognized, and at least three processes are supported in the literature. These are (1) exsolution, (2) simultaneous crystallization, and (3) replacement. Obviously a wide range of conditions may be expected, and variables to be considered are temperature, pressure, concentrations, and time. Optimum conditions for rigid structural control are probably approached in exsolution. Likewise, the simultaneous crystallization of two feldspars in an oriented intergrowth, assuming such a process is possible, would take place under conditions highly favorable to rigid structural control. Early-formed crystals react with magma to produce uniform crystals of different composition. Such magmatic reactions grade into deuteric alteration, and the line demarking deuteric alteration from high temperature replacements which are hydrothermal is truly an elusive one. However, under conditions of relatively low temperatures and with highly aqueous rather than magmatic concentrations, it is not difficult to visualize a sloughing-off of structural control with increasing importance being relegated to openings and ease of circulation. Atomic structure remains an important factor under such conditions in influencing or determining the location of the openings. These views, the writers believe are essentially those propounded by Andersen,[21] except that primary importance is here attached to the control of atomic structure rather than to contraction cracks to explain the orientations of the lamellae.

The writers should like to emphasize that under conditions favorable to structural control, it seems quite probable that intergrowths of rather similar appearance could result from all three suggested processes. If such be the case, optical continuity, regularity of pattern, and even, size, distribution, and orientation of blebs, may be of little avail as criteria for determining the process of formation of certain perthites.

The literature affords many examples of differences of opinion as to the origin of specific perthites. In all fairness, it should also be said that textural differences are not the sole reason for seeking different genetic processes to explain different perthites. Genetic theories and experimental data have played a considerable part, and the problem is a complicated one. A brief speculation as to the origin of the Tory Hill perthite may serve to bring out a few of the difficulties.

## Application to Tory Hill Perthite

The Tory Hill perthite is a composite of several textural varieties. The genesis of these varieties may be distinct and unrelated, but it appears equally probable that the development may have been continu-

[21] *Op. cit.*, p. 162.

ous with the evolution of the textural varieties dependent upon a gradually changing physical environment.

Of the textural varieties in the Tory Hill perthite, film perthite has generally been assigned to exsolution; patch perthite, to replacement. The evidence for these assignments need not be reviewed here, but if both of these processes have been operative, an important question arises. This is whether the braid and vein perthites represent one or both of these processes or the third process, that of simultaneous crystallization. In review of the properties of the braid perthite, the following points are significant.

1. The braid perthite represents a strikingly regular arrangement of albite spindles oriented parallel to (110) and $(1\bar{1}0)$. *En echelon* groups are superimposed one on the other to form the braid which is approximately parallel to the trace of (100).
2. The albite and microcline are in optical continuity.
3. Polysynthetic twinning is poorly developed in the albite spindles and is entirely lacking in many.
4. Measurements on several thin sections of the regular braid perthite indicate about 58 per cent of albite by volume.
5. The braid perthite appears to grade into a variety designated as vein or band perthite.

If an origin by simultaneous crystallization of albite and microcline is assumed for the braid perthite, the history of the development may be postulated. Contemporaneous crystallization of albite and microcline containing a small amount of soda feldspar in solid solution resulted in the braid perthite. Subsequently, albite films were developed in the microcline by exsolution. Patch perthite was later developed by replacement. Difficulty arises in explaining the vein perthite which is a transition type between the braid and the patch perthites. This variety most nearly resembles the vein perthite characteristic of granite pegmatites attributed by Spencer to simultaneous crystallization. Polysynthetic twinning in the albite is well developed; the microcline is coarsely twinned, and the two feldspars are in optical continuity. The writers believe this vein or band perthite to represent replacement, and although the simplicity of the explanation given above for the development of the Tory Hill perthite is appealing, a more complicated history is indicated.

Attention has been called to the similarity of the Tory Hill perthite to Ceylon moonstone, especially in the crystallographic directions developed. Spencer[22] has demonstrated that the moonstones represent orthoclase-microperthites and cryptoperthites formed by exsolution. His

[22] *Mineral. Mag.*, **22**, 291–368 (1930).

explanation of the genesis of the Ambalangoda moonstone may have application to the origin of the Tory Hill perthite. The textural relations have been briefly described in a preceding section. According to Spencer, two solid-solution changes have occurred in the moonstone. A single solid-solution phase first separated into (Or,Ab) perthite at about 900–1000°C. The (Or) and (Ab) phases, representing solid solutions containing different proportions of potash and soda feldspar components, are believed to have had rather similar physical properties. The (or,ab) microperthite and cryptoperthite separated from the (Or) and (Ab) phases at about 500–700°C. and developed mainly along the plane of schiller $(13.0.\bar{2})$. As a consequence of this second solid-solution change the (Or) and (Ab) phases no longer existed. They are recognizable now only because there are different proportions of (or) and (ab) in the areas of the original (Or) and (Ab) phases.

The moonstones constitute an orthoclase-microperthite series with a soda-feldspar content ranging from 4 to 52 per cent. If the many albite strings and films in the soda-rich moonstone from Ceylon were gathered into areas of pure albite, and the orthoclase into areas of relatively pure potash feldspar containing a few residual films of albite, and if during this process, the orthoclase were converted to microcline, the result would be a braid-like perthite similar to the Tory Hill perthite. If also, subsequent to this process and possibly as a direct continuation of magmatic processes, deuteric or hydrothermal alteration occurred with albitization of the early-formed feldspar, the braid perthite would be converted in part to vein or band perthite, passing finally into patch perthite. The orthoclase-microcline relationships are but little known, and the writers are hesitant in advancing any details of the processes, but certain observations may be cited which support the generalized origin presented.

Spencer[23] has described a microcline-microperthite from a pegmatite in the vicinity of the Ambalangoda moonstone mine. This intergrowth has a bulk composition of 76.5, K-f; 20.4, Na-f; 3.1, Ca-f. The perthitic structure is described as being regular but much coarser than in the moonstone microperthite. The separation of the albite lamellae is said to be more complete, and this fact is correlated with the conversion of the feldspar to microcline. The change is said to have taken place probably at temperatures above 700°C. from a single homogeneous potash-soda-feldspar phase and was accompanied by complete exsolution of the soda-feldspar component in the form of albite lamellae which are oriented for the most part along the perthite plane, but also in part along (010).

[23] Spencer, E., *Mineral. Mag.*, **22,** 327–330 (1930).

The moonstones or members of the orthoclase-microperthite series are readily homogenized by heat-treatment. In comparison with the moonstones, the microcline-microperthites were found by Spencer[24] to be resistant to heat-treatment, but the finely twinned microclines much less so than the coarsely twinned varieties. These experimental data are, in part, the basis for assigning the moonstones to an exsolution origin and the microcline perthites to simultaneous crystallization. Spencer emphasizes the fact that multiple twinning in the vein albite and the coarse twinning in microcline indicate that a rigid triclinic symmetry has been developed in these feldspars. He points out that multiple twinning is not present in the albite films of exsolution origin. The absence of multiple twinning in many of the albite blebs making up the braid perthite and the association of this albite with finely twinned microcline is suggestive, at least if the above criteria are accepted, that braid perthite may, in some manner, be connected with exsolution from a phase which originally was of monoclinic or near monoclinic symmetry.

To complete the round of suggestions, certain observations are presented which indicate a possible origin of the braid perthite, at least in part, by replacement.

1. Transition of the braid perthite into vein and patch types establishes replacement as an operative process in the history of the perthitic development.

2. Perthitic feldspars are common in the syenites intimately related to the pegmatite. Two photomicrographs (Plate II-F, and Fig. 2) illustrate these perthites. The amount of albite in the perthites ranges from a few stringers, which appear to be related to a marginal development of albite on microcline, to a marked preponderance of the soda feldspar. There is little doubt but that these perthites, in part at least, represent replacement, probably deuteric or high-temperature hydrothermal. Veinlets of molybdenite and pyrrhotite in the syenites support this view. However, it is interesting to note that there is an absence of multiple twinning in the albite lamellae.

An alternate suggestion, therefore, is that the braid perthite may have originated, in part, by the process of exsolution and, in part, by replacement. Andersen[25] has shown that there are textural transitions between string perthites and vein perthites. He believes that vein perthite may be formed from string perthite by a process of recrystallization which involves both the microcline and the albite strings. As a result the microcline loses its fine twinning and becomes the ordinary cross-twinned variety. The recrystallization, according to Andersen, is governed by

[24] *Mineral. Mag.*, **22**, 363–364 (1930); **24**, 480–486 (1937).
[25] *Op. cit.*, p. 165.

contraction cracks and by fluxing agents. Usually the recrystallization is accompanied by addition of soda feldspar, and transitions from vein perthite into chess-board albite are common.

The Ambalangoda moonstone represents a high-temperature feldspar which by exsolution on relatively rapid cooling resulted in orthoclase-microperthite and cryptoperthite. The Tory Hill feldspar with its high soda feldspar content and regularity of pattern bearing similarities to the moonstone may represent a microperthite of very similar magmatic origin. However, subsequent to the initial crystallization, a more complicated history is indicated than in the case of the moonstones. The idea of recrystallization under near-magmatic conditions possibly accompanied by replacement seems a reasonable one to the writers to account for the origin of the braid perthite. The vein and patch perthites were formed by replacement. This process may have been a continuation of magmatic processes and was accompanied by the development of rigid triclinic symmetry in both the sodic and potassic feldspar components.

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