

THE ORIGIN OF ANTIPERTHITES FROM SOME CHARNOCKITIC ROCKS IN THE NEW JERSEY PRECAMBRIAN

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ABSTRACT

In the Precambrian of northern New Jersey a granite and a plagioclase gneiss are intimately interlayered and presumably had a similar *p-T* history.

Plagioclase in the K₂O-deficient gneiss ranges in composition from An₃₃ to An₅₀, Or_{2.4} to Or_{6.9}, and is always antiperthitic. The microcline blebs and mantles from the antiperthitic plagioclase of the gneiss are submicroscopic perthites with a total Ab content of 15.5 percent (mostly as exsolved albite) and a delta value of 0.74.

Plagioclase from the granite ranges from An₂₂ to An₃₅, Or_{2.4} to Or_{6.5} and antiperthite was not observed. Microcline from the granite is perthitic with an average total Ab content of 20.1 percent, and a delta value of 0.73.

Two alternate hypotheses are offered for the origin of the antiperthite. (1.) The exsolution of microcline from plagioclase is permitted by the structure of plagioclase between An₃₃ to An₅₀. Exsolution of microcline does not occur in plagioclase of An₂₂ to An₃₂. (2.) The development of antiperthite is dependent upon the feldspar phase that crystallizes first. In the granite, the K-feldspar crystallized first; in the gneiss, the plagioclase crystallized first and the small amount of microcline then nucleated on low-energy surfaces of the plagioclase, such as twin planes, grain boundaries and crystal imperfections.

GEOLOGIC SETTING

The New Jersey Highlands cross the northern part of the state as a 20 mile-wide belt of mostly Precambrian rocks between the Triassic Newark Basin to the southeast and the Paleozoic Valley and Ridge province on the northwest. During the 1940's the U. S. Geological Survey carried out studies in the vicinity of certain magnetic deposits and this led to the modern maps and reports of Sims (1953), Hotz (1953) and Buddington and Baker (1961). In recent years, B. L. Smith has completed the mapping of the Highlands as a whole; a report on this work is being published. The present paper reports results derived from a detailed local study suggested during the regional work.

Figure 1 shows the distribution of two major rock groups in the Highlands: (i) the granites and (ii) pyroxene gneisses. In this map, the first group includes all granitic and syenitic rocks. In general these rocks consist of about equal quantities of quartz, microcline perthite and plagioclase together with a few percent of hornblende. Pyroxene generally

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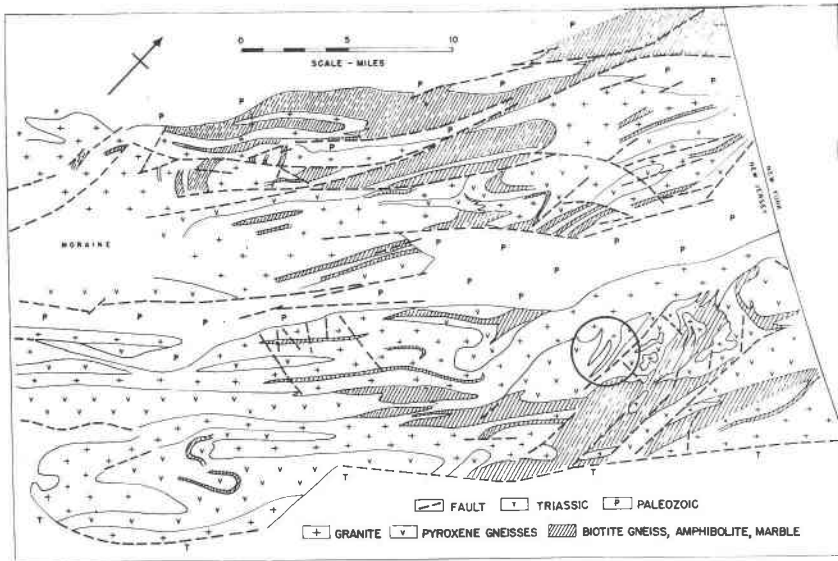


FIG. 1. Distribution of the granites and pyroxene gneisses in the New Jersey Precambrian Highlands. The circle represents the areas studied in detail.

takes the place of hornblende in a northeast-southwest trending central zone of the Highlands. Alaskitic, syenitic, sodic and other facies of the granite group are quantitatively unimportant, making up much less than five percent of the total; the granite is notably uniform in mineral composition in the area as a whole.

In Figure 1, the pyroxene gneiss group includes rocks with a typical mineral composition of 5 to 20 percent quartz, 55 to 70 percent andesine, and pyroxene. Over substantial areas ortho- and clinopyroxenes typically are found together. These rocks mostly show compositional layering with charnockitic affinities and are found mainly in a northeast-southwest trending central zone in contrast to the distribution of the other principal rock types of the Highlands found mainly near the northwest and southeast margins—(i) marbles, (ii) biotitic quartzo-feldspathic gneisses and (iii) amphibolite and pyroxene amphibolite.

ROCK TYPES

The area of detailed study is one in which the hornblende granite and quartz, two-pyroxene gneiss are interlayered and intimately associated (Fig. 1). Goodspeed (1967), studying trends in an area immediately to the north, has shown that the granite is remarkably homogeneous, whereas the orthopyroxene, clinopyroxene and quartz content of the

TABLE 1. REPRESENTATIVE MODAL ANALYSES

Sample	Plagioclase Gneiss			Hornblende Granite
	11	24A	46A	Average of 62 samples (Goodspeed, 1967)
Plagioclase	70.0	63.6	64.2	28.6
Quartz	6.3	17.5	3.0	28.6
Microcline	0.0	0.0	2.4	32.4
Orthopyroxene	15.5	5.5	14.2	0.0
Clinopyroxene	1.3	7.4	6.6	tr.
Hornblende	4.2	3.4	8.2	6.0
Biotite	0.0	0.0	0.0	0.5
Accessories	2.1	2.4	2.8	5.0

gneiss varies considerably. Modal analyses of the granite and the gneiss are given in Table 1.

The hornblende granite consists of nearly equal amounts of perthitic microcline, plagioclase and quartz with a small amount of hornblende. Garnet is observed locally. The plagioclase of the granite is not visibly antiperthitic under magnification of 1000 \times . The plagioclase of the gneiss is always antiperthitic.

TEXTURE OF THE ANTIPERTHITE

The microcline blebs of the antiperthitic plagioclase are extremely irregular in distribution and size within a given thin section. The distribution of the very fine and medium-size microcline blebs (some are less than 0.001 mm in diameter) is controlled almost entirely by twin planes (Fig. 2A and 4). The coarser microcline is often irregularly distributed within a grain (Fig. 2), mantling grain boundaries as well as impurities within the plagioclase grains. Similar textures have been described by others, most recently Carstens (1967) who observed that the irregular distribution of blebs is common to much antiperthitic plagioclase and not necessarily a criterion for origin. The different textures produced by antiperthites compared to perthites, regardless of origin, may be explained by the slow rate of diffusion in plagioclase compared with that in alkali feldspar. In plagioclase K must exchange for Ca and Na, and Al-Si tetrahedron bonds must be broken (Goldsmith, 1952). The textures do indicate that the microcline blebs and mantles crystallized late, after the formation of twin planes, and grain boundaries.

PREPARATION OF SAMPLES

After crushing to a size range of 0.124 to 0.074 mm, the samples were

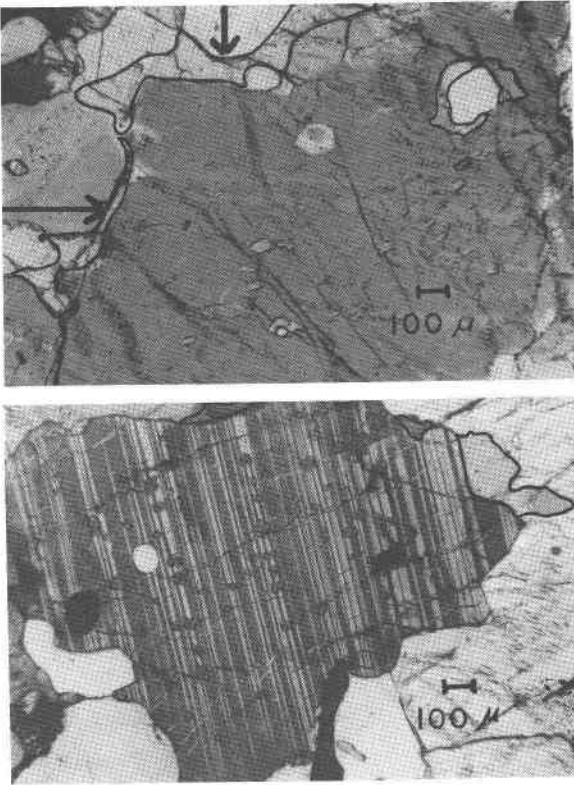


FIG. 2(A) Antiperthitic plagioclase. The arrows point to mantles of microcline which have been outlined in ink. Note the quartz grain within the plagioclase, in the upper right quarter, which is also mantled by microcline. Polars partly crossed. Microcline has been stained. (B) Antiperthitic plagioclase with small mantles of microcline outlined in ink. Note twin control of microcline blebs. Crossed polars.

run through a Frantz magnetic separator to remove all but the minerals with lowest magnetic susceptibility. Apatite was removed by gravity separation using heavy liquids. When appropriate (see below) microcline was separated by liquid flotation.

Samples for X-ray vacuum spectrometer analysis were prepared using the heavy absorber-fusion method of Rose *et al.* (1962).

FELDSPAR ANALYSES

Plagioclase and quartz could not be easily separated because their densities are too similar. Bulk K_2O and CaO contents were determined for the mixture of quartz and plagioclase in the combined fraction by

X-ray spectrochemical analysis. Reproducibility of the analyses was within two percent of reported results.

Plagioclase compositions were determined by the Tsuboi method (Tsuboi, 1923). Vogel (1968) showed that this method was as accurate as refractive index α determinations. Six to twenty grains were measured from each sample; little or no variation in composition was observed within a given sample. The accuracy and precision of the Tsuboi method in this composition range is 0.5 mole percent An (Vogel, in prep.).

Figure 5A shows the ratio of K_2O to CaO of the plagioclase from the hornblende granite and plagioclase gneiss; Figure 5B presents these same data calculated as mole percent Or versus mole percent An in plagioclase. The most important feature of Figures 5A and 5B is that they demonstrate that the plagioclase from the plagioclase gneiss contains about the same K_2O percent as the plagioclase from the hornblende granite.

In many samples of plagioclase gneiss all of the microcline occurs as blebs within plagioclase grains or as mantles around the grains (Fig. 2, 3, and 4). To determine the total microcline related to the antiperthite, the total quartz-feldspar fraction was separated thus avoiding the freeing of microcline blebs and mantles. Detailed textural studies in the thin sections insured that no "primary" grains of microcline were in the rocks selected for quartz-feldspar separations.

Figure 5C represents data from the antiperthitic plagioclase in which the microcline mantles have been included in the K_2O/CaO determination. The calculated Or mole percent ranged from 2.3 to 16.0.

Microcline analyses to determine the Ab in solid solution and the total Ab (exsolved plus that in solid solution) were made using the $\bar{2}01$ method (Orville, 1963, 1967). Relative structural states were determined

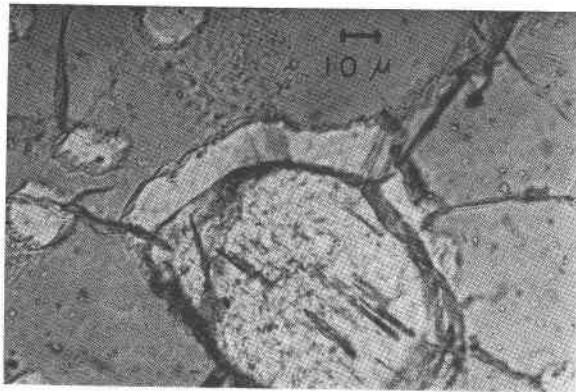


FIG. 3. Orthopyroxene inclusion in antiperthitic plagioclase which is mantled by microcline. Crossed polars.

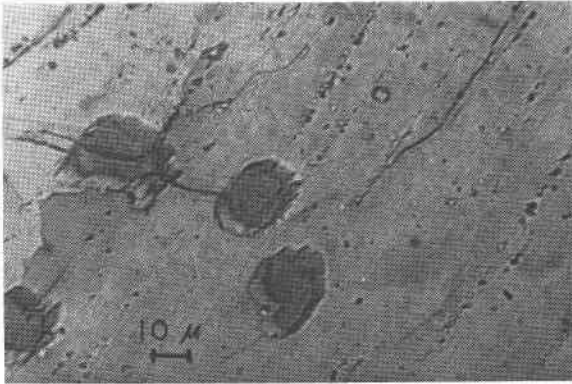


FIG. 4. Very small microcline blebs are in composition plane of twins. Larger microcline areas in lower left quarter. Crossed polars.

(Δ values) (Dietrich, 1962; Orville, 1967) on microcline from both rock types. To determine the total Ab in the microcline, microclines were homogenized by heating at 1050°C for at least 12 hours. Some samples, during a total heating time of 48 hours, were periodically checked at short time intervals to ascertain when homogenization was complete; it was found that eight hours was sufficient.

The data collected from the feldspars of the hornblende granite and plagioclase gneiss are summarized in Table 4. The plagioclase from the granite contained an average of 26.5 mole percent An and 5.2 mole percent Or and no antiperthite. The microcline from the granite had a total average Ab content of 20.1 mole percent, of which 1.8 mole percent was in solid solution and the remainder was in exsolved form. The Δ values averaged 0.74.

The plagioclase from the gneiss ranged in composition from 33 to 49 mole percent An, averaging 42.4 percent. The Or percent averaged 4.6 mole percent exclusive of the microcline mantles, or 8.4 percent (ranging from 2.3 to 16.0 percent) with the thin microcline mantles included. The structural states of the plagioclases from both rock types were highly ordered, as determined by the intermediacy index (Slemmons, 1962) and the plot of the poles of late-stage deformation twins (Vogel, 1964).

Although most samples of the plagioclase gneiss contain no free microcline, it was possible by fine grinding and repeated separation to free some of the microcline mantles and blebs of the antiperthitic plagioclase for analyses. No perthite was observed optically in these microclines; however, diffractometer analyses of all samples show well defined albite peaks. The total average Ab content of the microcline blebs and mantles

from the gneiss was 15.5 mole percent Ab of which 14.0 percent represented exsolved albite and 1.5 percent was in solid solution.

WHOLE ROCK ANALYSES

X-ray spectrographic analyses for K_2O and CaO were made on samples selected from a traverse across the hornblende granite—plagioclase contact, taken at 200-foot intervals on both sides of the contact. The results of these chemical analyses plus analyses on the feldspars are shown in Table 2.

DISCUSSION

The hornblende granite has a high K_2O content, averaging about 4.7 percent, yet the plagioclase from this granite are not optically antiperthitic. The gneiss is low in K_2O and the plagioclase from the gneiss is always antiperthitic regardless of the amount of total K_2O present. The K_2O content of plagioclase from the granite was about the same as the K_2O content of the plagioclase from the plagioclase gneiss. (See Table 4 for summary of the data.) In one example the whole rock contains only 0.27 percent K_2O , yet the plagioclase was visibly antiperthitic. Plagioclase from the granite may be also antiperthitic, but the optical resolu-

TABLE 2. WHOLE ROCK ANALYSES FOR K_2O AND CaO COMPARED WITH ANALYSES OF CONTAINED PLAGIOCLASE AND MICROCLINE. SAMPLES COLLECTED ACROSS CONTACT AT INTERVALS OF 200 FEET

Sample No.	Whole Rock			Plagioclase			Microcline	
	K_2O	CaO	K_2O/CaO	K_2O/CaO	An%	Or% ^a	Ab% Total	Δ Value ^b
96	4.37	1.92	2.28	0.18	25.0	5.5	21.0	0.73
97	4.86	1.67	2.91	.21	22.5	5.9	22.0	.71
99	4.72	1.58	2.99	.21	24.5	6.5	24.5	.74
100A	3.18	2.57	1.24	.17	32.0	6.8	14.0	.72
100	0.40	7.57	0.05	.04	46.0	2.3	— ^c	
101	0.27	5.88	0.05	.05	49.0	3.0	— ^c	
103	0.76	7.72	0.09	.08	41.5	4.7	— ^c	
104	1.07	3.92	0.27	.32	34.0	13.6	16.5	
105	No analysis			.22	35.0	9.4	14.5	.76
106	1.08	3.94	0.27	.28	36.0	12.6	16.0	.71
108	1.36	4.05	0.34	.30	34.0	15.5	15.5	.74

^a Orthoclase percent calculated.

^b 12.5 ($d_{131} - d_{131}$).

^c Although plagioclase is antiperthitic, the microcline blebs are extremely small (less than 100 μm) and could not be separated.

tion of the microscope is too low to allow such antiperthite, if present, to be observed. With high power it is possible to resolve optically microcline blebs as small as 0.001 mm in diameter. The microcline blebs are easily observed because of the strong contrast in refractive indices of the plagioclase host and the blebs. Bambauer *et al.* (1967) and Corlett and Ribbe (1967) found that almost all plagioclase specimens examined were "micro- and/or crypto-antiperthitic" (Bambauer *et al.*, 1967, p. 339).

The lack of apparent contact effects and the lack of textural or compositional zoning in the granite near the contact, in addition to the intimate and conformable interlayering of the two rock types indicate that they have been subjected to the same temperature and pressure history, at least from some point in the past to the present. Earlier differences may have existed but they have been obliterated by subsequent strong metamorphic and/or plutonic activity.

TABLE 3. PAIRS OF ANALYSES OF ANTIPERTHITIC PLAGIOCLASE. THE FIRST ANALYSIS IN EACH PAIR WAS MADE ON THE ENTIRE FELDSPAR FRACTION. THESE SAMPLES WERE CAREFULLY SELECTED FROM DETAILED STUDIES OF STAINED THIN SECTIONS TO MAKE CERTAIN THERE WERE NO "PRIMARY" GRAINS OF MICROCLINE; ALL OF THE MICROCLINE PRESENT IS AS BLEBS OR MANTLES. THE SECOND ANALYSIS (S), HAS HAD ALL OF THE FREE MICROCLINE SEPARATED

Sample no.	An mole percent	K ₂ O/CaO	Calculated Or mole percent
11	47	.06	3.5
11(S)	47	.06	3.5
13	46	.08	4.6
13(S)	46	.08	4.6
54	37	.16	7.4
54(S)	37	.10	5.0
42A	44	.12	5.9
42A(S)	44	.09	4.8
54A	42	.12	6.2
54A(S)	42	.11	5.6
46	35	.27	11.8
46(S)	35	.13	5.8
46A	41	.32	16.0
46A(S)	41	.12	6.2

TABLE 4. SUMMARY OF ANALYSES OF PLAGIOCLASE AND MICROCLINE FROM THE PLAGIOCLASE GNEISS AND HORNBLÉNDE GRANITE

<i>Granite</i>	<i>Plagioclase Gneiss</i>	
<i>Plagioclase</i>	<i>Plagioclase</i>	
An ₂₂ -An ₃₅	An ₃₃ -An ₄₉	
\bar{X} = 26.5%	\bar{X} = 42.4%	
S.D. = 3.6%	S.D. = 3.6%	
Or _{2.4} -Or _{6.3}	(1) Or _{2.3} -Or _{6.9}	(2) Or _{2.3} -Or _{16.0}
\bar{X} = 5.2%	\bar{X} = 4.6%	\bar{X} = 8.4%
S.D. = 1.7%	S.D. = 1.4%	S.D. = 7.3%
(No antiperthite observed)	(Antiperthite present in all samples)	
<i>Microcline</i>	<i>Microcline</i>	
Total Ab in microcline	Total Ab in microcline	
\bar{X} = 20.1%	\bar{X} = 15.5%	
S.D. = 2.8%	S.D. = 2.9%	
Albite not exsolved	Albite not exsolved	
\bar{X} = 1.8%	\bar{X} = 1.5%	
S.D. = 1.7%	S.D. = 1.5%	
Structural State	Structural State	
Δ = 0.73	Δ = 0.74	
Whole Rock	Whole Rock	
K ₂ O = 4.3-4.9%	K ₂ O = 0.3-1.4%	
CaO = 1.6-1.9%	CaO = 3.9-7.7%	

(1) Microcline mantles separated.

(2) Microcline mantles included.

Sen (1959) pointed out the importance of the availability of potassium in the environment to the amount of KAlSi_3O_8 in solid solution in the plagioclase. "... an increased relative concentration of potassium in the environment will enrich the plagioclase in potassium up to a point, which will be determined by the limits of solubility." (Sen, 1959, p. 488). The amount of KAlSi_3O_8 in the plagioclase of the granite should represent the upper limit of solubility for the environmental conditions that existed during crystallization of the plagioclase. Potassium may be in the matrix as very small volumes of microcline rather than being in solution as part of an isomorphic series, similar to Laves' (1952) quasi-homogeneous perthites.

The amount of microcline in the plagioclase of the plagioclase gneiss is highly variable. Some of the microcline blebs and mantles of the antiperthitic plagioclase are lost by separating the free microcline from the sample with a heavy liquid (2.6 specific gravity). Table 3 shows that if

the microcline content of the antiperthitic plagioclase is high (greater than five percent) some loss of microcline will occur upon processing. The result is a narrowing of the microcline content of the plagioclase. The only free microcline in many samples of the gneiss is that which mantles the plagioclase grains. Although it is possible that the mantles may not be related to the antiperthite, the optical and X-ray characteristics of the microcline mantles and blebs are identical and the textures indicate that they formed by the same process. Some of these mantles are in optical continuity with blebs and occasionally physically connected.

The composition and structural states of the microcline blebs and mantles from the antiperthitic plagioclase are very constant. These are all submicroscopic perthites. Hubbard (1965) observed that the microcline blebs and mantles from the antiperthites that he studied were perthites. The Δ value of his microclines was 0.12 (structurally disordered) in contrast to 0.74 for microclines of this study. Hubbard (1965) also observed zoning in the plagioclase near the alkali feldspar contacts. No zoning was observed in this study. Hubbard (1965) concluded that a homogeneous potassium-rich andesine exsolved an alkali feldspar which itself exsolved upon cooling.

It is difficult to understand why the plagioclase from the gneiss is antiperthitic in contrast to the nonantiperthitic nature of the plagioclase from the granite. If the amount of KAlSi_3O_8 in the plagioclase from the hornblende granite represents the upper limit of solubility, then the plagioclase from the gneiss should not be expected to be saturated in KAlSi_3O_8 since the gneiss contains one-third the K_2O of the granite and both appear to have crystallized (perhaps recrystallized) under similar pressure, temperature and volatile conditions.

The difference in the composition of the plagioclase from the two rock types may be important. The plagioclase from the gneiss ranges from 33 to 49 mole percent anorthite whereas the plagioclase from the granite ranges from 22 to 34 percent. The reason for the development of antiperthite in the plagioclase gneiss may be structural rather than petrological. The formation of antiperthites could be related to the structural discontinuities that were first documented by Doman *et al.* (1965)

Goldsmith (1952) has pointed out the difficulties in exsolving potassium feldspar from plagioclase because of the different Al:Si ratios. However, the presence of the peristerites (Laves, 1954; Ribbe, 1960) and other apparently exsolved plagioclase is evidence that breaking and rearrangement of the Al-O and Si-O tetrahedrons does occur. Recent studies by Korekawa and Jagodzinsky (1967) and Nissen *et al.* (1967) indicate that the superstructure and schiller observed in some labradorites is probably caused by some type of exsolution.

The writers offer two possible interpretations for their data. The first

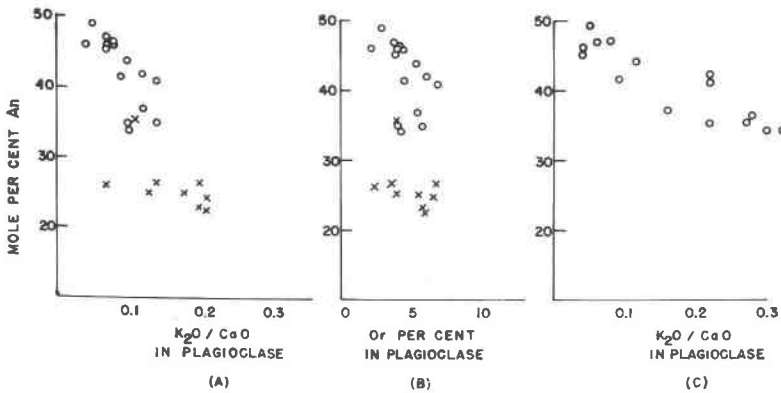


FIG. 5. Analyzed plagioclase. All free microcline has been separated. The symbol \circ represents plagioclases from plagioclase gneiss, the symbol \times represents plagioclases from hornblende granite. (A) K_2O/CaO (B). Mole percent Or calculated from the data in (A). (C) K_2O/CaO of analysed antiperthitic plagioclase in which all of the microcline mantles are included.

is that the exsolution of microcline from plagioclase is compositionally controlled. Doman *et al.* (1965) and Bambauer *et al.* (1967) have observed that the low structural state plagioclase series is divided into linear segments. The occurrence of breaks in the plagioclase series at simple Si:Al ratios indicates that these segments represent structural differences within a low structural series, with the more albitic part of the segments being the most ordered (Doman *et al.* 1965). The development of antiperthitic plagioclase in the rocks studied is entirely confined to one of these linear segments (An_{33} to An_{50}), with a suggested trend of decreasing K_2O/CaO ratio with increasing anorthite in this segment (Figure 5C). No antiperthite is observed in the plagioclase from the granite and these plagioclase are (with one exception) confined to the An_{15} to An_{33} segment and would be in the upper part of this segment.

The alternate interpretation is that the development of antiperthite depends upon which feldspar phase crystallized first. The plagioclase of the granite is not antiperthitic because the composition of the rock is such that microcline crystallized first or at the same time as plagioclase and separate crystals were formed. The composition of the plagioclase gneiss was such that the plagioclase crystallized first and the small amount of microcline which crystallized later, nucleated on the low-energy surfaces of the plagioclase such as twin planes, grain boundaries and crystal imperfections. The microcline crystallized on and replaced the plagioclase crystals. That the microcline from the granite and from

the plagioclase gneiss crystallized under the same conditions is indicated by their similar composition, structural state, and perthitic nature.

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