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Relationship between geological occurrences and twinning laws of plagioclase in granitic and metamorphic rocks in the Sør Rondane Mountains, Antarctica

Yuhei TAKAHASHI*, Yoshiaki TAINOSHO**, Yasuhito OSANAI*** and Noriyoshi TSUCHIYA†

Yuhei TAKAHASHI, Yoshiaki TAINOSHO, Yasuhito OSANAI and Noriyoshi TSUCHIYA (1997) Relationship between geological occurrences and twinning laws of plagioclase in granitic and metamorphic rocks in the Sør Rondane Mountains, Antarctica. *Bull. Geol. Surv. Japan*, vol.48(6), p.305-312, 4figs.,1table.

Abstract: Twinning laws of plagioclase were determined for granitic and metamorphic rocks in the Sør Rondane Mountains in Antarctica.

Granitic rocks in this area are subdivided on the basis of their emplacement mode into discordant and concordant types. C-twins, which are defined as all type of twins except albite and pericline twins, are more dominant in the discordant-type bodies than in the concordant-type bodies. This result agrees fairly well with the previous studies showing that the C-twins are common in typical intrusive rocks (i.e., those with discordant boundaries to surrounding rocks). However, the frequency of C-twinning in the discordant-type intrusive rocks in this area is often less than that of typical intrusive rocks in Japan. The C-twins in previous studies might have been overestimated because of ambiguity in optical methods at that time.

Frequency of pericline twinning is locally variable in the high-grade metamorphic rocks in the study area. This suggests that the frequency is not only dependent on metamorphic temperature but also on local differences of shear stress.

1. Introduction

Mode of twinning laws of plagioclase has been used in the discussion of geological setting for plutonic and metamorphic rocks. For example, Gorai (1951) suggested that C-twins, which are defined for all the twinning types except the albite and pericline twins, especially carlsbad and albite-carlsbad twins, occur in typical intrusive rocks (those with discordant boundaries) but rarely in metamorphic rocks. Suwa *et al.*(1974) pointed out that the frequency of twinned plagioclase with composition plane (010) is related to the temperature of metamorphism. However, the controling mechanism of plagioclase twin formation that lies behind the observed relationship is unclear. In fact, different interpretations for formation of plagioclase twins have been proposed. Wenk (1973, 1977, 1988) found that the C-twins are more common in the metamorphic rocks in the central Alps than accepted hitherto. Wenk (1969) and Borg and Heard (1970) have produced pericline twinning of plagioclase under high shear stress conditions at high temperature. Based on the study of high grade metamorphic rocks in Greenland, Olsen and Kohlstedt (1985) proposed that the formation of either albite twins or pericline twins is dependent on shear stress strength.

Recently many Japanese geologists have studied the Sør Rondane Mountains in East Antarctica and have clarified petrology and geochemistry of granitic and high-grade metamorphic rocks (e.g. Tainosho *et al.*, 1992; Asami *et al.*, 1992). The geological setting of our samples is, hence, clear. In this article, we describe the plagioclase twinning laws of granitic and metamorphic rocks of this area, and we will reexamine the empirical relationship between frequency of plagioclase twinning type and geological occurence.

*Hokkaido Branch, GSJ (present duty; JICA expert in Mongolia)
**Faculty of Human Development, Kobe University; 3-11 Tsuruko Nada-ku, Kobe, Hyougo 657 Japan
***Present address; Faculty of Education, Okayama University; 3-1-1 Tsushimanaka, Okayama, 700 Japan
†Faculty of Engineering, Tohoku University; Aoba, Aramaki, Aoba-ku, Sendai, Miyagi, 980 Japan

Keywords: twinning law, plagioclase, C-twins, pericline twin, Antarctica

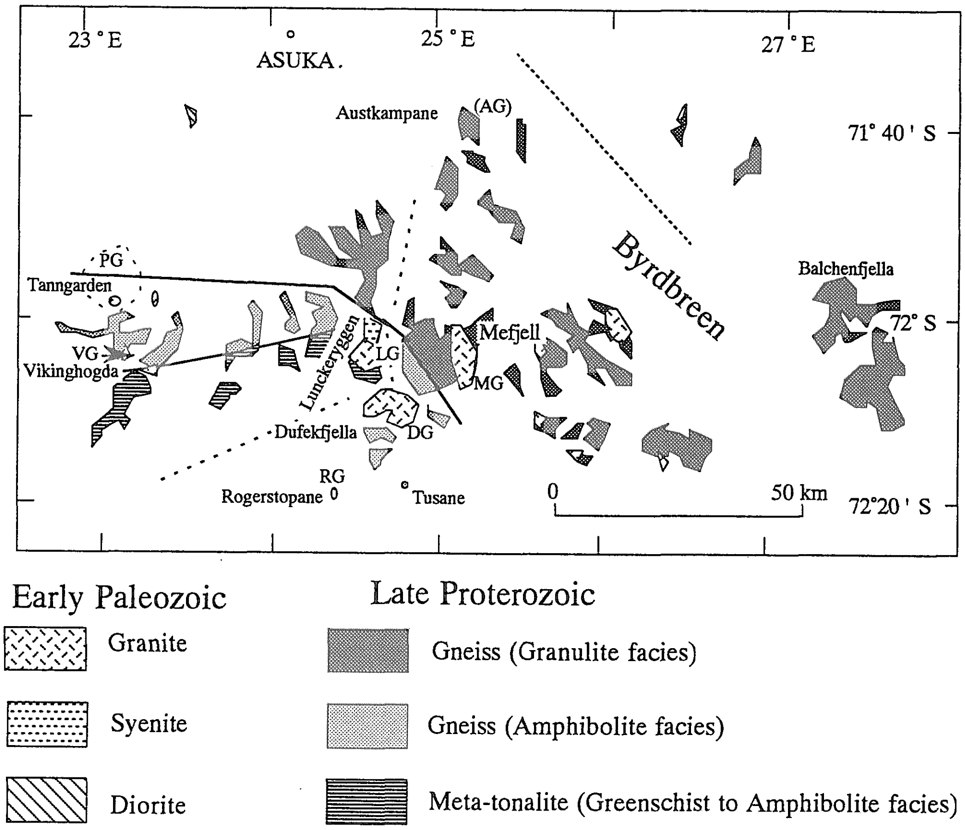

Fig. 1 Generalized geologic map, modified after Shiraishi and Kagami (1992)
Solid and broken thick lines show faults and concealed faults, respectively. Abbreviations are names of the granitic masses (see text). Broken circle of PG (Pingvinane granite) show the deduced exposure area under the glacier (white). AG (Austkampane granite) is not drawn because of its small size.

2. Outline of geology

The Sør Rondane Mountains are one of the largest inland mountain ranges in East Antarctica, occupying an area of about 250 km long and 100 km wide (Fig. 1). The area consists of metamorphic rocks of Late Proterozoic age (Shiraishi and Kagami, 1992) and plutonic rocks and minor dikes of latest Proterozoic to early Paleozoic age (Tainosho *et al.*, 1992; Takigami *et al.*, 1992).

The majority of the metamorphic rocks are pelitic, psammitic and intermediate gneisses, associated with subordinate basic and calc-silicate gneisses. The metamorphic rocks can be structurally divided into a number of lithologic units. The geochemical characteristics of the protoliths of each unit permit a subdivision into oceanic type, island-arc type, accretional complex type and continental island-margin type (Osanai *et al.*, 1992). Regional metamorphism was of medium-pressure type amphibolite- to granulite-facies (Asami *et al.*, 1992).

Plutonic rocks of granitic, syenitic and dioritic composition are widespread, and some have had a contact metamorphic effect on the surrounding rocks. The granitic rocks are mostly granite (s. s.) with minor granodiorite and quartz monzonite modal compositions. Most of the granitic rocks show chemical characteristics of A-type granitoids and are suggested to be volcanic arc granites or within-plate granites based on incompatible elements (Tainosho *et al.*, 1992).

3. Modes of plagioclase twinning laws

3.1 Method for determining twinning laws

Plagioclase twinning laws were determined by optical method using a universal stage (Takahashi, 1995). That is, the twinning laws were determined by measuring the extinction angle in the zone perpendicular to the composition plane and using the diagrams of Suwa *et al.*(1974) and Suwa (1977).

3.2 Mode of plagioclase twinning laws in granitic rocks

3.2.1 Description

Twinning laws of plagioclase were determined for several granitic rocks including the Vikingh-

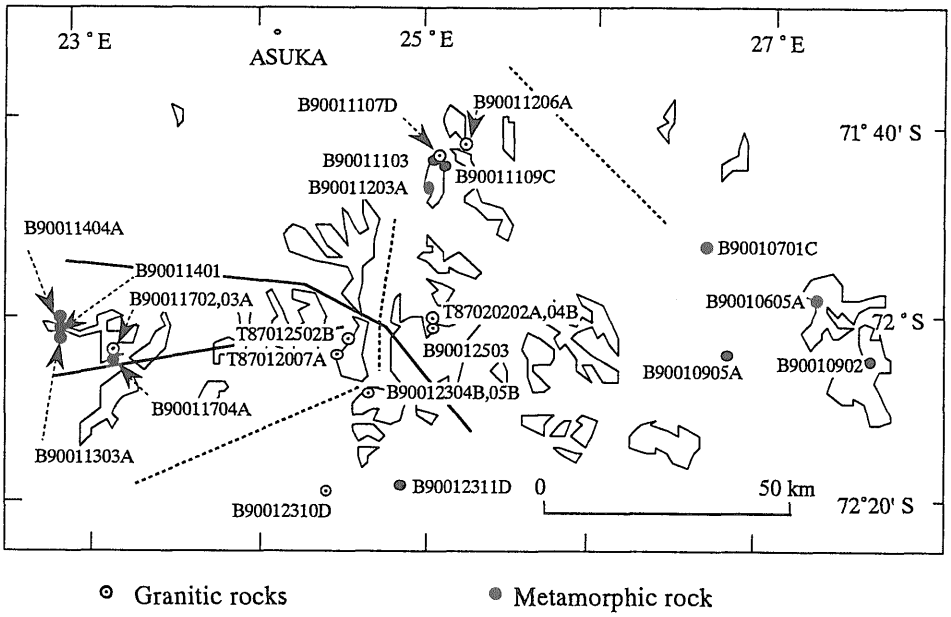

Fig. 2 Map showing the sample locations.

Table 1 Modes of plagioclase twinning laws.
No. of each samples is used in Fig.3 and 4.

Granitic rocks

Type	Discordant granite				Small intrusives		Concordant granite			Migmatitic granite		Unknown
	Lunckeryggen		Dufekfjellet		Austkampane		Mefjell			Vikinghogda		Rogerstopane
sp.no.	T87012502	T87012007a	B90012304b	B90012305b	B90011107d	B90011206a	B90012503	T87020204b	T87020202a	B90011703a	B90011702	B90012310d
No.	LG1	LG2	DG1	DG2	AG1	AG2	MG1	MG2	MG3	VG1	VG2	RG
Carlsbad	1	2		2	4	1	2					2
Ab-Ca	3		2	2	3	5		1			1	
Albite	20	18	17	16	18	16	17	5	29	23	24	23
Ab-Pe					1			3				
Pericline						1	1	13	1			
Others			1		1	1	1					
Total	24	20	20	20	27	24	21	22	30	23	25	25

Metamorphic rocks

	Balchenfjella		Krakken	Kaggen	Austkampane			Tanngarden			Vikinghogda	Tsusane
sp.no.	B90010605a	B90010902	B90010701c	B90010905a	B90011109c	B90011103	B90011203a	B90011303a	B90011401	B90011404a	B90011704a	B90012311d
No.	M01	M02	M03	M04	M05	M06	M07	M08	M09	M10	M11	M12
Ab-Ca										1	1	
Albite	29	20	47	38	49	50	38	24	38	23	48	29
Ab-Pe	4	26	2					12	7	8	1	18
Pericline	7	4	1	2	1		2	14	5	18		3
Total	40	50	50	40	50	50	40	50	50	50	50	50

Abbreviation: Ab-Ca;Albite-Carlsbad, Ab-Pe;Albite-Pericline

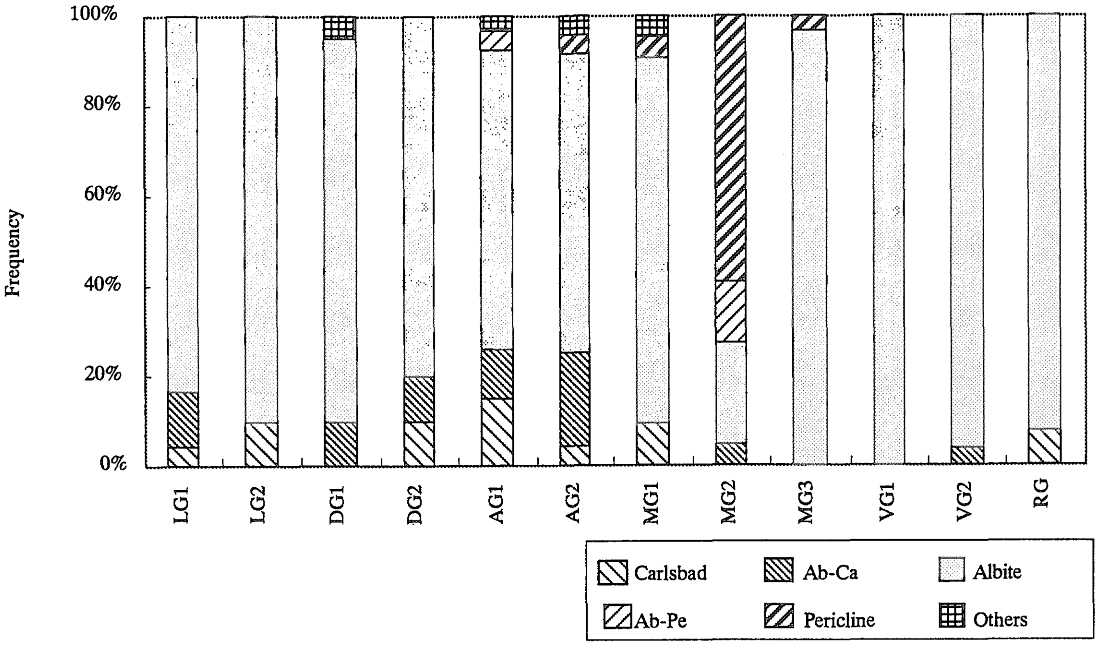

Fig. 3 Frequency of plagioclase twinning laws in granitic rocks (for No. see Table 1).

ogda granite (VG in Fig.1), the Mefjell complex (MG), the Lunckeryggen granite (LG), the Dufek granite (DG), the Austkampane granite (AG) and the Rogerstopane granite (RG). Locations of the samples are shown in Fig.2. On the basis of field occurrences, Tainosho *et al.*(1992) divided these rocks into a migmatitic granite (VG), a concordant stock (MG) and discordant stocks (LG and DG). AG is composed of a number of small intrusive bodies such as dikes and sheets. The exposure of RG is limited due to cover by a glacier, so its geological setting is unclear. Plagioclase twinning data of these rocks are shown in Table 1 and Fig. 3.

The Vikinghogda granite has intruded the metamorphic rocks concordantly. It has weak foliation parallel to the boundary and contains blocks of the metamorphic rocks with diffuse boundaries. Plagioclase twinning of the Vikinghogda granite is mostly according to the albite law with subordinate albite-carlsbad law twinning (B90011703a and B90011702). The frequency of C-twinning, which are defined as all twins besides albite and pericline twins (Gorai, 1951), is 0 to 4 %.

The Mefjell complex is composed of quartz monzonite and granodiorite with quartz diorite dikes. The boundary of the intrusive complex is parallel to gneissosity of the surrounding gneisses. Plagioclase twinning in the quartz monzonite (B90012503) is mostly according to the albite law with minor of carlsbad, albite-ala B and pericline twinning. The frequency of C-twinning is 10 %. In the granodiorite (T87020204b), pericline law twinning is most common, followed by albite law and albite-carlsbad law twinning. The frequency of C-twinning is 4 %. Plagioclase twinning in the quartz diorite (T87020202a) is mostly the albite law with minor of pericline law twinning. The frequency of C-twinning is 0 %.

Plagioclase twinning in the Lunckeryggen granite is mostly by the albite law, followed by carlsbad law and albite-carlsbad law (T87012502 and T87012007A). The frequency of C-twinning is 10 to 17 %.

Plagioclase twins in the Dufek granite are mostly albite twin, followed by carlsbad twin and albite-carlsbad twin (B90012304b and B90012305b). Manebach twinning is also identified in one grain. The frequency of C-twinning is 10 to 20 %.

The Austkampane granite is a general name of various kinds of small granitic masses, dike and sheet intrusions into the gneiss, in Austkampane. Plagioclase twinning is investigated in both a granitic dike (B90011107d) and a granitic sheet (B90011206a). In both bodies, albite twinning is common, followed by carlsbad and albite-carlsbad twinning. Albite-ala B and pericline twins are of minor occurrence. The frequency of C-twinning is 25 % in both.

Most plagioclase twinning law in the Rogerstopane granite is albite law with minor carlsbad twinning (B90012310d). The frequency of C-twinning is 8 %.

3.2.2 Relationship between field occurrences and plagioclase twinning of the granitic rocks

The frequency of pericline twinning is minor in the granitic rocks except in the granodiorite of the Mefjell complex. In granitic rocks, the frequency of C-twinning systematically changes, so we discuss the relationship between field occurrence and frequency of C-twinning in each intrusive body.

The frequency of C-twinning increases in the following order: migmatitic granite (VG), a concordant stock (MG), discordant stocks (LG and DG) and small intrusive bodies (AG). Gorai (1951) and Suwa (1956) pointed out that C-twins are more abundant in typical intrusive rocks than in metamorphic rocks and intrusive rocks conformable to metamorphic rocks.

The result of the present study generally supports the conclusions of Gorai (1951) and Suwa (1956) but it is different in detail. In our study, granitic rocks are roughly divided into discordant and concordant types. The discordant type intrusives, LG, DG and AG, correspond to typical intrusive rocks. The frequency of C-twinning in the discordant type intrusives in the study area is often less than that in typical intrusive rocks of Gorai (1951). These differences result from the difference in the method by which the twinning laws were determined and from ambiguity of the optical method. Gorai's method makes use of an ordinary petrographic microscope without a universal stage. Some of C-twins in Gorai's method should be exactly A-twins. For example, if a fragment of an albite twinned plagioclase grain shows only two lamellae and composition plane is not perpendicular to the thin section, twinning resembles carlsbad twinning. In addition, though a distinction between albite-ala B and albite twins is difficult for oligoclase and andesine, a lot of albite-ala B twins were classified as C-twins in previous works. Thus C-twins in previous studies might be overestimated.

3.3 Mode of plagioclase twinning laws in the metamorphic rocks

3.3.1 Description

Plagioclase twinning laws are determined for gneisses which contain quartz and plagioclase of oligoclase to andesine composition. The samples are selected in large area in order to discuss regional variation and the effect of granitic intrusion (Fig. 2). Plagioclase twinning data of these rocks are shown into Table 1 and Fig. 4.

Balchenfjella: The exposures in Balchenfjella, in eastern part of the Sør Rondane Mountains, are formed by high-grade gneissic rocks accompanied by migmatites and small bodies of intrusive rocks. The metamorphic grade attained the hornblende-granulite facies, followed by amphibolite - facies metamorphism

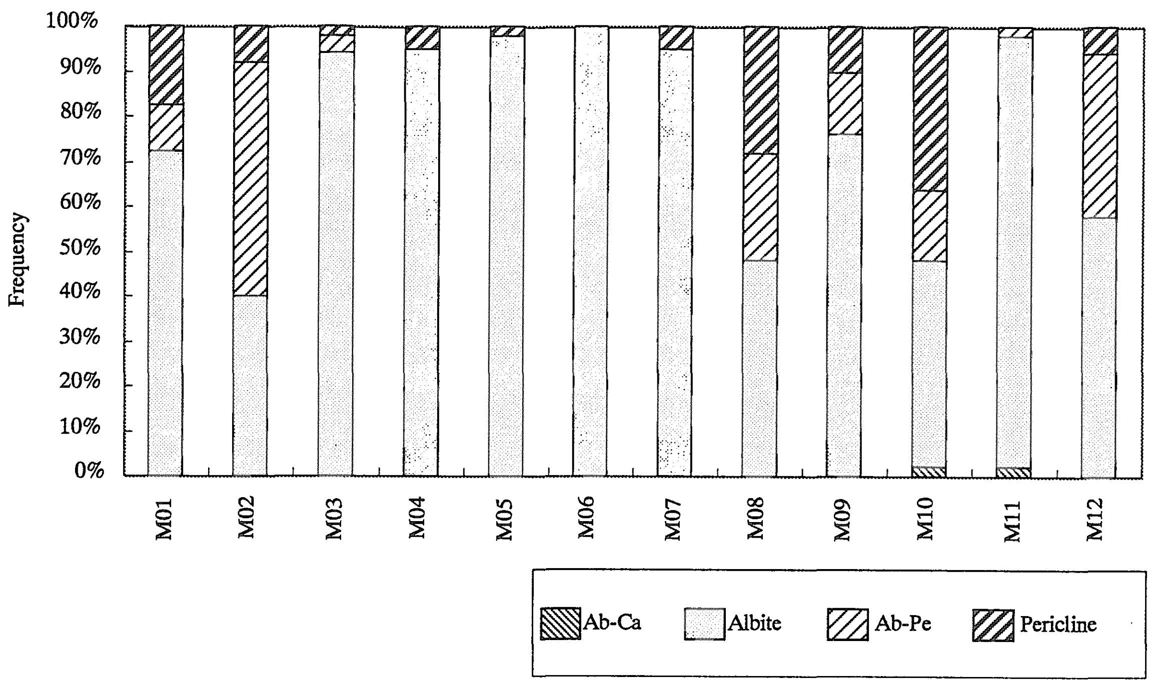

Fig. 4 Frequency of plagioclase twinning laws in metamorphic rocks (for No. see Table 1).

(Asami *et al*., 1992). No large intrusive masses occur in the area.

Plagioclase twinning in the samples of Balchenfjella inland, B90010605A and B90010902, is according to albite, albite-pericline and pericline laws. The frequency of pericline twinning is 28 and 60 %. In the samples from the nunatak west of Balchenfjella, B90010701C and B90010905A, plagioclase twinning occured mostly by the albite law with minor of albite-pericline and pericline twinning. The frequency of pericline twinning is 5 and 6 %.

Austkampane: In Austkampane, north of the central mountains, the metamorphic grade of the gneisses attained the upper amphibolite facies, followed by retrograde metamorphism. In this area, a lot of small dikes and sheets intruded into the gneisses though there is no large intrusive body in the area.

The plagioclase twinning determined for three samples, B90011103, B90011109C and B90011203A is mostly of the albite law. The frequency of pericline twinning is 0 to 5 %.

Tanngarden and Vikinghogda: Tanngarden and Vikinghogda are located at the west of the study area. In Tanngarden, large granitic stock (Pingvinane granite; PG in Fig.1) intruded the gneisses with concordant to discordant boundaries. Plagioclase of the gneiss is mostly twinned according to the albite, albite-pericline and pericline laws with subordinate albite-carlsbad twinning as shown in B90011303A, B90011401 and B90011404A. The frequency of pericline twinning is 24 to 52 %.

In the Vikinghogda area, a migmatitic granite (Vikinghogda granite) intruded into the gneiss with a concordant boundary. Plagioclase of the gneiss (B90011704A) is mostly twinned by the albite law with minor twinning of the albite-carlsbad and albite-pericline laws. The frequency of pericline twinning is 2 %.

Tusane: Tusane is located at the southern end of the central Sør Rondane Mountains. In this area, high - grade metamorphic rocks are exposed. The geologic setting of this area is not clear due to covering by a glacier. Plagioclase twinning of the gneiss (B90012311D) is of the albite and albite-pericline laws with minor pericline twinning. The frequency of pericline twinning is 42 %.

3.3.2 Variation of frequency of pericline twin in the metamorphic rocks

The rocks of the Sør Rondane Mountains show a high metamorphic grade, that is, upper amphibolite to granulite facies. Previously, Suwa *et al*.(1974) concluded that the frequency of composition plane (010) decreases with increasing metamorphic temperature , from the greenschist to the granulite facies. Their conclusion implies that the frequency of pericline twin occurrence increases with increase of the metamorphic grade. Our results are in disagreement with this as they show that the frequency of pericline twinning locally changes in the high-grade metamorphic rocks in the Sør Rondane Mountains.

In western part of the study area, the frequency of pericline twinning is variable, that is, it is rare in Austkampane and Vikinghogda but it is common in Tanngarden. The samples in Tanngarden are collected near to a stock-like granitic body (PG), so pericline twins in the samples were produced by forceful intrusion, comparable to an example from the Ryoke metamorphic rocks near forceful granitic intrusion (Takahashi and Nishioka, 1994).

Also in the eastern part of this area, the frequency of plagioclase twinning in the gneisses by the different laws is variable. But the interpretation of variation of the frequency of pericline twinning in this area is difficult because no forceful granitic stocks occur in this area. It may be inferred that the shear stress that accompanied the recrystallization was locally different. The experiments of Wenk (1969) and Borg and Heard (1970) showed that pericline twins can be produced under a shear stress field. In our case, the frequency of pericline twinning in the gneisses is clearly not dependent on the degree of metamorphism, but it may be depend on local difference of shear stress.

4. Summary

Our analysis of plagioclase twinning laws in the granitic and metamorphic rocks in Sør Rondane Mountains has shown that:

(1) C-twins, all twins except albite and pericline laws, are more dominant in the discordant type granitic bodies than in the concordant type granitic bodies.

(2) In the discordant type intrusives, the frequency of C-twinning is often less than that observed in the typical intrusive rocks in previous studies.

(3) The frequency of pericline twinning is variable in the high-grade metamorphic rocks.

(4) From this fact it is interpreted that the frequency is not only dependent on the degree of metamorphism but also on local differences of shear stress.

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斜長石双晶出現頻度と産状の関係
－東南極セールロンダーネ山地の花崗岩類及び変成岩類を例として－

高橋裕平・田結庄良昭・小山内康人・土屋範芳

要　旨

斜長石双晶様式の岩石学的な経験則を検討するためセールロンダーネ山地の花崗岩類と変成岩類中の斜長石の双晶タイプの出現状況を検討した.

花崗岩類は貫入様式に基づき，大きく調和的なものと非調和的なものに分けられる．アルバイト及びペリクリン以外の双晶様式で定義されるC双晶が非調和的な花崗岩類によく産する．これは従来の経験則を大局的に支持する．しかしながら非調和的な花崗岩類のC双晶の頻度は，従来各地で報告されている非調和的な貫入様式を示す典型的な貫入岩中の頻度に比してやや少ない．これは従来の研究では光学的決定法の不確かさが十分考慮されていなかったことによる.

変成岩類は角閃岩からグラニュライト相に至る高度変成岩類である．これらに含まれる斜長石のペリクリン双晶に注目するとその頻度は変成度と無関係に地域毎に変化する．このことは変成温度の上昇によりペリクリン双晶の頻度が大きくなることでは説明できず，地域毎の剪断応力の違いを反映していることで説明できる.