PLAGIOCLASE IN YAMATO-7308 METEORITE FROM ANTARCTICA

Kanenori SUWA

Department of Earth Sciences, Faculty of Science, Nagoya University, Chikusa-ku, Nagoya 464

and

Kenzo YAGI

Hokusei Gakuen College, Oyachi, Shiroishi-ku, Sapporo 061-01

Abstract: Twinning patterns, optical angles, Köhler angles, and other optical properties and chemical compositions of the calcic plagioclases in Yamato-7308 meteorite from Antarctica were examined. The Yamato-7308 meteorite is a howardite consisting of polymict breccia of eucrite and diogenite fragments.

Plagioclases occur as individual grains in matrix, as a main constituent of eucrite fragment, and as maskelynite in eucrite fragment. These plagioclases have petrographical characteristics exhibiting their different petrogenetical processes.

Plagioclase grains in eucrite fragment are twinned after the albite-Carlsbad, albite and pericline laws, and show rarely the Carlsbad law. Frequency percentage of the albite-Carlsbad and Carlsbad laws reaches 45%. Average composition of the plagioclase is $Or_{0.2}Ab_{10.3}An_{89.4}$.

Individual plagioclase grains in matrix are twinned after the pericline and albite laws, and the albite-Carlsbad law is rare. Frequency percentage of the pericline law reaches 76%, and that of the albite-Carlsbad law is only 4%. Average composition of the individual plagioclase grains is $Or_{0.1}Ab_{7.9}An_{92.0}$.

The twinning pattern of plagioclases in eucrite fragment clearly differs from that of individual plagioclase grains in matrix. Concerning the twinning pattern of plagioclase, Yamato-7308 meteorite contains two contrastive kinds of plagioclases: igneous type (in eucrite fragment) and metamorphic type (in matrix).

These plagioclases are considered to have been formed under the same genetical environment. Regional metamorphism occurred in an asteroid after its eucrite crust and diogenite mantle were formed. Individual plagioclase grains were formed by the regional metamorphism and eucrite fragments retain their original igneous characteristics owing to their situation far from the metamorphic terrain or their resistance to the regional metamorphism. Howardite was formed by collision between the partly metamorphosed asteroid and some meteoritic body.

Some individual plagioclase grains show clear shadow extinction and kink bands, and plagioclase in some eucrite fragments is maskelynitized either completely or locally. These facts indicate that some individual grains and some rock fragments have been subjected to intense impact metamorphism by the collision.

1. Introduction

Yamato-7308 meteorite that weighed 480 grams was collected by Mr. K. SHIRAISHI and others from the bare ice field to the southeast of the Yamato Mountains, 71°49′S, 36°16′E, on the 22nd of December, 1973 (SHIRAISHI *et al.*, 1976).

The Yamato-7308 meteorite is a howardite consisting of polymict breccia of eucrite and diogenite fragments. This meteorite was fully described petrographically by YAGI *et al.* (1978) and its pyroxenes were examined crystallographically by TAKEDA *et al.* (1976).

Plagioclases occur as individual grains with or without clear shadow extinction in matrix, as lath-shaped crystals showing ophitic texture with pigeonite in eucrite fragment, as equigranular grains showing adcumulus texture with pyroxene in eucrite fragment, and as maskelynite in eucrite fragment. These plagioclases have the respective petrographical characteristics exhibiting their different petrogenetical processes.

In this paper, these petrographical features of the plagioclases in the Yamato-7308 meteorite are especially described and petrogenetical processes induced by the petrographical features of these plagioclases are discussed.

2. Petrography and Mineralogy of Yamato-7308 Meteorite

2.1. *General petrography*

The Yamato-7308 meteorite was found as a complete individual, 9.0×7.5×4.5 cm^3 in size, with a black fusion crust 0.5 mm in thickness and white to pale gray, fresh interior, and the boundary between the crust and the interior is sharp.

The following descriptions are based mainly on YAGI *et al.* (1978) and partly on TAKEDA *et al.* (1976).

In thin section, the meteorite is heterogeneous, containing individual mineral grains and eucrite and diogenite fragments up to 2 to 3 mm in size (Figs. 3a and 3b).

The medium-grained matrix is composed of pyroxene, plagioclase, and opaque minerals.

Eucrite fragments have ophitic textures consisting of pigeonite and lath-shaped plagioclase (Figs. 5a and 5b), and sometimes adcumulus textures comprising equigranular grains of pyroxene and plagioclase (Figs. 6a, 6b, 7a and 7b). Mosaic aggregates of recrystallized plagioclase and pyroxene are rarely present.

Diogenite fragments show fine- to medium-grained mosaic aggregate of orthopyroxene (Figs. 11a and 11b). The characteristic texture of the diogenite fragment composed of equigranular aggregate of orthopyroxene with low birefringence shows a feature which led to it having been mistaken for anorthosite

Table 1. Modal composition of the Yamato-7308 meteorite (YAGI et al., 1978).

Matrix and fragment	100.0
Chondrule	—
Total	100.0
Olivine	0.4
Orthopyroxene	69.6
Clinopyroxene	12.8
Plagioclase	13.1
Opaque phase*	2.3
Silica minerals**	0.1
Devitrified glass	0.7
Others***	1.0
	100.0

* Opaque phase includes kamacite, troilite, chromite, taenite, and ilmenite.
** Silica minerals include quartz and tridymite.
*** Others include apatite, whitlockite, zircon, monazite, baddeleyite and spinel.

fragment by YAGI *et al.* (1978).

Modal analysis of the Yamato-7308 meteorite is shown in Table 1 (YAGI *et al.*, 1978).

2.2. *Pyroxenes*

Pyroxenes are orthopyroxene, pigeonite, augite and clinohypersthene, in the decreasing order of abundance. Some pyroxene grains show various grades of shadow extinction and kink bands.

Orthopyroxene compositions are $Wo_{3-1}En_{36-78}Fs_{61-21}$. Orthopyroxenes contain exsolved lamellae of clinohypersthene, of which the (100) plane and b-axis are parallel to those of the host orthopyroxene.

Pigeonite compositions are $Wo_{10-8}En_{37-60}Fs_{53-31}$. Optical angle of the pigeonite is always less than 15°. Twinning is common, and the pigeonite shows exsolution lamellae of augite. Fe-rich pigeonite crystals ($Wo_{10}En_{37}Fs_{53}$) with regular exsolution lamellae of augite ($Wo_{42}En_{32}Fs_{26}$) on (001) of the host clinohypersthene ($Wo_{2}En_{39}Fs_{59}$) were found both as a mineral fragment and in a eucrite fragment.

Augite compositions are $Wo_{46-39}En_{45-30}Fs_{9-30}$. Augites occur as individual grains, as exsolution lamellae in pigeonite, and as a reaction rim around the orthopyroxene. Some augites have the composition of subcalcic augite ($Wo_{28}En_{26}Fs_{46}$). Clinohypersthene compositions are $Wo_{2-4}En_{39-53}Fs_{59-43}$.

2.3. *Plagioclase and other constituents*

Plagioclase is next to orthopyroxene in abundance and has compositions $Or_{0-1}Ab_{2-20}An_{98-80}$ ($Or_0Ab_9An_{91}$ on average). Detailed description on the plagioclase is given in the next chapter.

Olivine ($Fo_{61}Fa_{40}$) is rare, and two polymorphs of silica, quartz and tridymite, are rarely found. Opaque phases include kamacite, troilite, chromite, taenite and ilmenite, in the decreasing order of abundance. Accessories include apatite, whitlockite, zircon, monazite, baddeleyite, and spinel.

Small, brownish glass spherules, 0.1 to 0.5 mm in diameter, are present and are partly devitrified. Chemical compositions of the glass spherules (SiO_2 52.2, MgO 19.5, FeO 16.1, Al_2O_3 5.6, CaO 4.4) are very close to the bulk composition of the average composition of Yamato-7308 meteorite (SiO_2 51.1, MgO 22.0, FeO 16.0, Al_2O_3 3.6, CaO 3.5).

3. Plagioclases in Yamato-7308 Meteorite

3.1. *Introduction*

Plagioclases occur as maskelynite in eucrite fragment, as lath-shaped crystals showing ophitic texture with pigeonite in eucrite fragment, as equigranular grains showing adcumulus texture with pyroxene in eucrite fragment, and as individual grains in matrix.

Twinning patterns, optical angles, Köhler angles, and other optical properties and chemical compositions of the plagioclases in Yamato-7308 meteorite are examined.

Plagioclases in Yamato-7308 meteorite are usually 0.1 to 0.5 mm in size. They are twinned after the various kinds of law, and usually show a very fine lamellar twinning.

The usual method for the determination of the twinning law is to measure optical elasticity axes, optical axes, composition plane and twinning axis, but this method is tedious and inconvenient in the case of very fine lamellar twinning.

The devised optical method to determine the twinning laws of plagioclases having the (010) and the rhombic section as composition plane (SUWA *et al.*, 1974; SUWA, 1977, 1978) was employed. This method is simple and convenient to discriminate the twinning laws even in the case of the fine lamellar twinning.

3.2. *Chemical composition*

The frequency distributions of chemical compositions of plagioclases in Yamato-7308 meteorite are shown diagrammatically in Fig. 1.

Plagioclase compositions are $Or_{0-1}Ab_{2-20}An_{98-80}$. Average composition of plagioclases is $Or_0Ab_9An_{91}$.

Chemical composition of the maskelynite in eucrite fragment is $Or_0Ab_{10}An_{90}$.

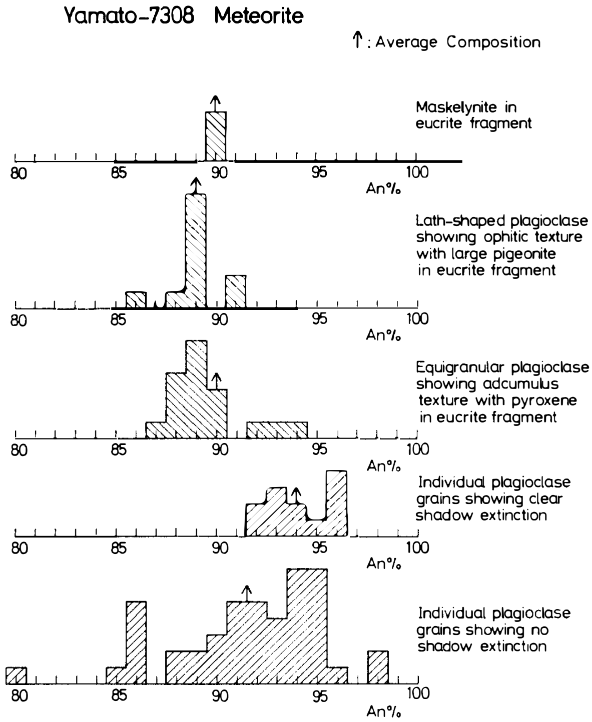

Fig. 1. The frequency distributions of chemical composition (An%) of maskelynite and plagioclases in eucrite fragments and of plagioclases occurring as individual grains in matrix of Yamato-7308 meteorite (howardite) from Antarctica.

Chemical compositions of lath-shaped plagioclases showing ophitic texture with pigeonite in eucrite fragment are $Or_{0-1}Ab_{9-13}An_{91-86}$ and their average composition is $Or_0Ab_{11}An_{89}$.

Chemical compositions of equigranular plagioclases showing adcumulus texture with pyroxene in eucrite fragment are $Or_{0-1}Ab_{6-13}An_{94-87}$ and their average composition is $Or_0Ab_{10}An_{90}$.

Chemical compositions of individual plagioclase grains showing clear shadow extinction are $Or_0Ab_{4-8}An_{96-92}$ and their average composition is $Or_0Ab_6An_{94}$.

Chemical compositions of individual plagioclase grains showing no shadow extinction are $Or_{0-1}Ab_{2-20}An_{98-80}$ and their average composition is $Or_0Ab_{8.5}An_{91.5}$.

Individual plagioclase grains in matrix are slightly calcic than the maskelynite and the plagioclase in eucrite fragment.

Zonal structure is not observed in general. However, some individual plagioclase grains in matrix show small compositional variations less than 3 An % within grains.

3.3. Twinning pattern

The frequency percentages of twinning laws of plagioclases in Yamato-7308

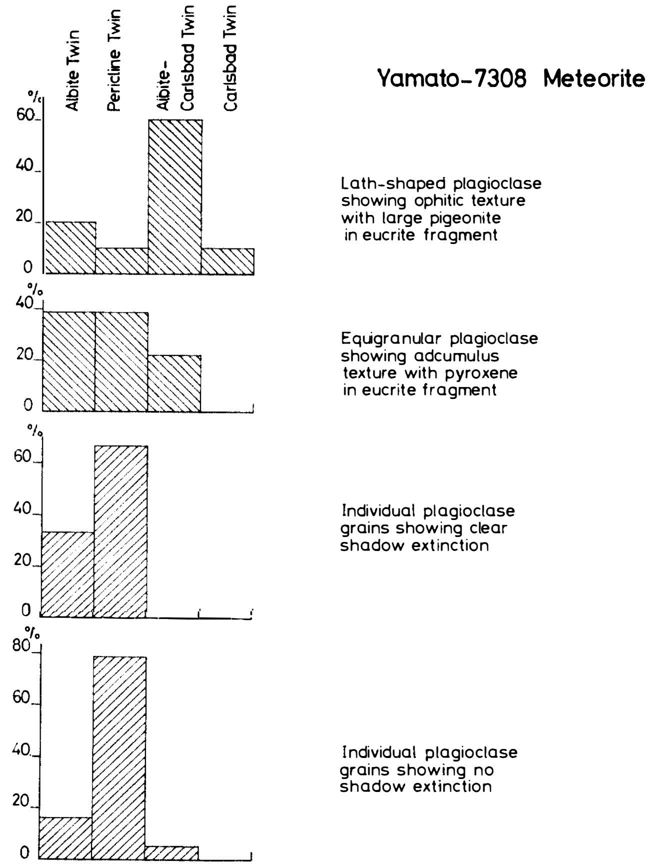

Fig. 2. The frequency percentages of twinning laws of plagioclases of four parts (two parts: eucrite fragments, two parts: individual grains) of Yamato-7308 meteorite (howardite) from Antarctica.

meteorite are shown diagrammatically in Fig. 2.

Lath-shaped plagioclase grains showing ophitic texture with pigeonite in eucrite fragment are twinned after the albite-Carlsbad law (6/10=60%) and the albite law (2/10=20%), and the occurrence of the Carlsbad law (1/10=10%) and the pericline law (1/10=10%) is small. The lath-shaped plagioclase grains in eucrite fragment are 0.2–0.6 mm in size (Figs. 5a and 5b).

Equigranular plagioclase grains showing adcumulus texture with pyroxene in eucrite fragment are polysynthetically twinned after the albite law (7/18=39%), the pericline law (7/18=39%), and the albite-Carlsbad law (4/18=22%). The equigranular plagioclase grains in eucrite fragment are 0.1–0.4 mm in size (Figs. 6a, 6b, 7a and 7b).

Individual plagioclase grains showing clear shadow extinction in matrix are 0.5–0.8 mm in size (Figs. 8a, 8b and 9), and are polysynthetically twinned, exclusively after the pericline law (4/6=67%) and albite law (2/6=33%).

Table 2. Frequency percentages of the composition plane (010) of plagioclase in Yamato-7308 meteorite and various igneous and metamorphic rocks.

	An0–24	An25–49	An50–74	An75–100
Eucrite fragment in Yamato-7308 meteorite[1]				61–90
Matrix in Yamato-7308 meteorite[1]				21–33
Bushveld anorthosite[2]			69 (An50–100)	
Plutonic rocks[3]	91	77	73 (An50–100)	
Volcanic rocks (phenocryst)[3]	80	77	80	83
Volcanic rocks (groundmass)[3]	100	91	94	89
Quebec anorthosite[2]			66	
Fiskenaesset anorthosite[2]				36
Granulite[4]		62	69	
Charnockite[5]		63	64	
Schist and gneiss[3]		75	75	33
Hornfels[3]		77	76	65
Paragneiss[6]		89		
Amphibolite[6]		88	87	73
Crystalline schist[7]	100			

[1] This paper, [2] SUWA (1979), [3] GORAI (1951), [4] SUWA (1966), [5] NAIDU (1954), [6] SUWA (1956), [7] TOBI (1961).

None is twinned after other laws.

Individual plagioclase grains showing no shadow extinction in matrix are 0.1–0.7 mm in size (Figs. 10a, 10b, 11a, 11b and 12), and are polysynthetically twinned after the pericline law (15/19=79%) and the albite law (3/19=16%). The occurrence of the albite-Carlsbad law (1/19=5%) is rare.

In the matrix of Yamato-7308 meteorite, the pericline law is predominant, reaching 76% and this twinning pattern clearly differs from that of eucrite fragment of Yamato-7308 meteorite.

The frequency percentages of the composition plane (010) in plagioclases in eucrite fragment and in matrix of Yamato-7308 meteorite are 71% and 24%, respectively (Table 2).

3.4. Köhler angle and optical angle

Data of Köhler angles and optical angles in the plagioclases twinned after the albite, pericline and Carlsbad laws are given in Tables 3, 4 and 5, respectively.

Table 3. Köhler angle and optical angle of plagioclases twinned after the albite law.

Composition	a $Or_1Ab_{10}An_{89}$	b $Or_0Ab_9An_{91}$
Occurrence	Equigranular plagioclase in eucrite fragment (Figs. 7a and 7b)	Individual plagioclase grain in matrix
$\widehat{XX}$	111°	114°
$\widehat{YY}$	135°	129°
$\widehat{ZZ}$	88°	92°
$\widehat{AA}$		57°
$\widehat{BB}$		176°
(−) 2V		79.5°

Table 4. Köhler angle and optical angle of plagioclases twinned after the pericline law.

Composition	c $Or_0Ab_5An_{95}$	d $Or_0Ab_5An_{95}$	e $Or_0Ab_4An_{96}$
Occurrence	Individual plagioclase grain in matrix (Figs. 10a and 10b)	Individual plagioclase grain in matrix (Fig. 12)	Individual plagioclase grain in matrix (Figs. 8a and 8b)
$\widehat{XX}$			102.5°
$\widehat{YY}$			127°
$\widehat{ZZ}$			104°
$\widehat{AA}$			53°
$\widehat{BB}$			170°
(−) 2V	78.5°	77°	77°

Table 5. Köhler angle of plagioclase twinned after the Carlsbad law.

Composition	f $Or_0Ab_{9.5}An_{90.5}$
Occurrence	Lath-shaped plagioclase in eucrite fragment (Figs. 5a and 5b)
$\widehat{XX}$	76°
$\widehat{YY}$	172.5°
$\widehat{ZZ}$	105°

4. Discussion

Yamato-7308 meteorite is a polymict breccia composed of fragments of diogenite and eucrite, set in a medium-grained matrix, and is classified as a howardite.

Pyroxenes in the howardite have a well-defined trend from En-rich to Fs-rich and they represent products of fractional crystallization (YAGI *et al.*, 1978).

In the eucrite fragment, anorthite (An_{86-94}) is always associated with fairly Fs-rich pigeonite. MCCARTHY *et al.* (1973) proposed a calculated composition of the eucrite parent liquid, which is very high in FeO and CaO. Throughout the fractionation of En-rich orthopyroxene, diogenitic fractions were formed, and the liquid moved toward the compositions further enriched in FeO, CaO and Al_2O_3. In such eucritic magma, nearly eutectic crystallization of anorthite and pigeonite fairly rich in Fs mole would occur, forming the eucritic fraction (YAGI *et al.*, 1978).

Lath-shaped plagioclase grains ($Or_0Ab_{11}An_{89}$) showing ophitic texture with pigeonite in eucrite fragment are twinned after the albite-Carlsbad and albite laws, and show rarely the Carlsbad and pericline laws. Frequency percentage of the albite-Carlsbad and Carlsbad laws reaches 70% together. This twinning pattern of the plagioclases clearly indicates an igneous origin for the ophitic eucrite fragment.

Equigranular plagioclase grains ($Or_0Ab_{10}An_{90}$) showing adcumulus texture with pyroxene in eucrite fragment are twinned after the albite, pericline and albite-Carlsbad laws. Frequency percentage of the albite-Carlsbad law reaches 22%. This twinning pattern of the plagioclases indicates an igneous origin for the adcumulus eucrite fragment.

Individual plagioclase grains ($Or_0Ab_8An_{92}$) with or without clear shadow extinction in the matrix are twinned after the pericline, albite and albite-Carlsbad laws. Frequency percentage of the pericline law reaches 76% and that of the albite-Carlsbad law is only 4%. This twinning pattern clearly differs from that of lath-shaped and equigranular plagioclase grains in eucrite fragment (Fig. 2).

The frequency percentages of the composition plane (010) in plagioclases in eucrite fragment and in matrix of Yamato-7308 meteorite are 71% and 24%, respectively.

Table 2 shows the frequency percentages of the composition plane (010) in Yamato-7308 meteorite and various igneous and metamorphic rocks. In volcanic rocks and ophitic eucrite fragment of Yamato-7308 meteorite, the frequency percentage is high and its variation in An % is very slight. In plutonic rocks, Bushveld anorthosite and adcumulus eucrite fragment of Yamato-7308 meteorite, the frequency percentage is higher and decreases slightly with increase of An %.

In granulite, charnockite, Quebec and Fiskenaesset anorthosite and matrix of Yamato-7308 meteorite, the frequency percentage is moderate and decreases markedly in calcic plagioclase.

As shown in Table 2, the frequency percentage of composition plane (010) is very low in calcic plagioclase in matrix of Yamato-7308 meteorite, Fiskenaesset anorthosite, schist and gneiss. It seems reasonable that many crystals twinned after the pericline law result from mechanical deformation.

Concerning the twinning pattern of plagioclase, it can be said that Yamato-7308 meteorite (howardite) contains two contrastive kinds of plagioclases: igneous type (in eucrite fragment) and metamorphic type (in matrix).

Individual plagioclase grains (An_{92}) in matrix are slightly calcic than maskelynite (An_{90}) and plagioclase (An_{90}) in eucrite fragment. Their compositional difference is actually small, and these plagioclases are considered to have been formed under the same genetical environment. It is considered that regional metamorphism provoking mechanical deformation occurred in an asteroid after its eucrite crust and diogenite mantle were formed. Individual plagioclase grains in matrix of this howardite are considered to have been formed by the regional metamorphism and the eucrite fragments in this howardite retain their original igneous characteristics owing to their situation far from the metamorphic terrain or their resistance to the regional metamorphism. Howardite consisting of polymict breccia of eucrite and diogenite fragments is considered to have been formed by collision between the partly metamorphosed asteroid and some meteoritic body.

Some individual plagioclase grains in matrix show clear shadow extinction and kink bands (Figs. 8a, 8b, and 9), and in some eucrite fragments plagioclase is maskelynitized either completely or locally (Figs. 4a and 4b). These facts indicate that some individual grains and some rock fragments have been subjected to intense impact metamorphism by the collision between the partly metamorphosed asteroid and some meteoritic body.

Acknowledgments

The meteorite studied here was placed at our disposal through the courtesy of Professor Takesi NAGATA, Director of the National Institute of Polar Research.

We would like to express our sincere appreciation to Professor Emeritus Seitaro TSUBOI of the University of Tokyo for his advice and encouragement. We are also indebted to Dr. Kazuhiro SUZUKI of Nagoya University for his kind assistance.

This work was supported in part by Grant-in-Aid for Scientific Research of the Ministry of Education, Science and Culture, and by the Ito Science Foundation, for which we would like to record our grateful thanks.

References

GORAI, M. (1951): Petrological studies on plagioclase twins. Am. Mineral., **36**, 884–901.

MCCARTHY, T. S., ERLANK, A. J. and WILLIS, J. P. (1973): On the origin of eucrites and diogenites. Earth Planet. Sci. Lett., **18**, 433–442.

NAIDU, P. R. J. (1954): Minerals of charnockites from India. Schweiz. Mineral. Petrogr. Mitt., **34**, 203–280.

SHIRAISHI, K., NARUSE, R. and KUSUNOKI, K. (1976): Collection of Yamato meteorites, Antarctica, in December 1973. Nankyoku Shiryô (Antarct. Rec.), **55**, 49–60.

SUWA, K. (1956): Plagioclase twinning in Ryoke metamorphic rocks from the Mitsue-mura area, Kii Peninsula, central Japan. J. Earth Sci., Nagoya Univ., **4**, 91–122.

SUWA, K. (1966): On plagioclases in metamorphic rocks from Lützow-Holmbukta area, East Antarctica. Proc. Japan Acad., **42**, 1175–1180.

SUWA, K. (1977): Precambrian anorthosites and their plagioclases. 2nd Prelim. Rep. Afr. Studies, Nagoya Univ., 3–12.

SUWA, K. (1978): Plagioclase twinning in Precambrian anorthosites. Natl. Geogr. J. India, **24**, 107–120.

SUWA, K. (1979): Plagioclase twin laws and fabrics in three specimens of anorthosite. Lithos, **12**, 99–107.

SUWA, K., MIZUTANI, S. and TSUZUKI, Y. (1974): Proposed optical method of determining the twinning laws of plagioclase. Mem. Geol. Soc. Japan, **11**, 167–250.

TAKEDA, H., MIYAMOTO, M., ISHII, T. and REID, A. M. (1976): Characterization of crust formation on a parent body of achondrites and the moon by pyroxene crystallography and chemistry. Proc. Lunar Sci. Conf. 7th, 3535–3548.

TOBI, A. C. (1961): Pattern of plagioclase twinning as a significant rock property. Proc. K. Ned. Akad. Wet., **64**, Ser. B., 576–581.

YAGI, K., LOVERING, J. F., SHIMA, M. and OKADA, A. (1978): Petrology of the Yamato meteorites (j), (k), (1) and (m) from Antarctica. Meteoritics, **13**, 23–45.

(Received June 11, 1979; Revised manuscript received July 15, 1979)

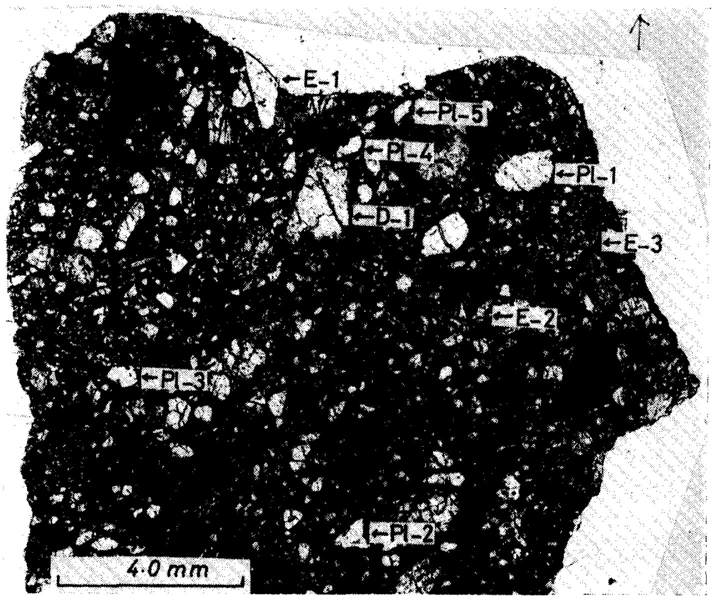

Fig. 3a. Photomicrograph of Yamato-7308 meteorite (howardite) from Antarctica. One nicol. E: Eucrite fragment, D: Diogenite fragment, Pl: Individual plagioclase grain, E-1: Maskelynite in eucrite fragment.

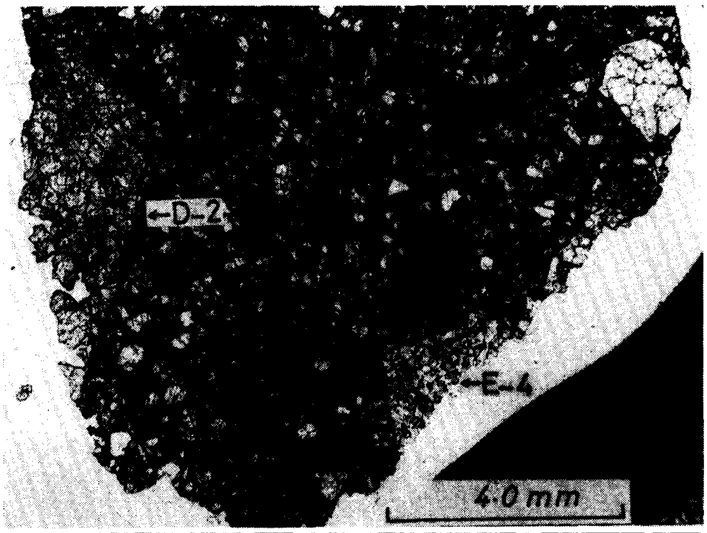

Fig. 3b. Photomicrograph of Yamato-7308 meteorite (howardite) from Antarctica. One nicol. E: Eucrite fragment, D: Diogenite fragment.

Fig. 4a. Maskelynite (Or_0Ab_{10}-An_{90}) *in eucrite fragment (center of this photomicrograph; E-1 in Fig. 3a) of Yamato-7308 meteorite (howardite) from Antarctica. One nicol.*

Fig. 4b. The same as Fig. 4a. Nicols crossed.

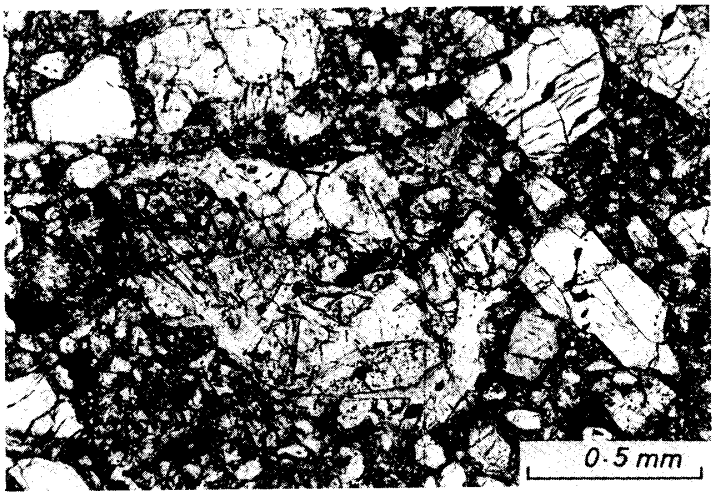

Fig. 5a. Lath-shaped plagioclase ($Or_0\ Ab_{11}\ An_{89}$) *showing ophitic texture with pigeonite in eucrite fragment (center of this photomicrograph; E-2 in Fig. 3a) of Yamato-7308 meteorite (howardite) from Antarctica. One nicol.*

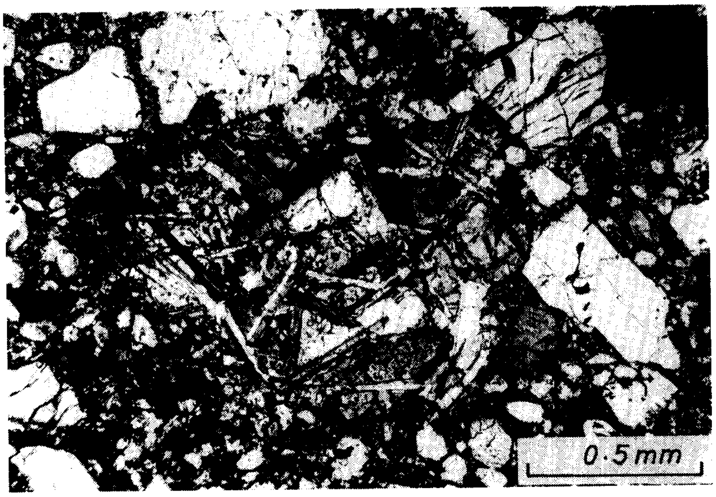

Fig. 5b. The same as Fig. 5a. Nicols crossed. The plagioclase grains are twinned after the albite-Carlsbad (60%) albite (20 %) pericline (10%) and Carlsbad (10%) laws.

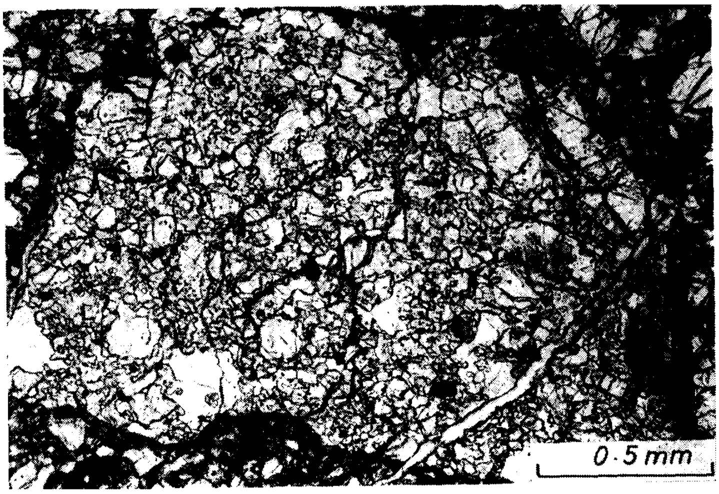

Fig. 6a. Equigranular plagioclase (Or_0 Ab_9 An_{91}) showing adcumulus texture with pyroxene in eucrite fragment (E-3 in Fig. 3a) of Yamato-7308 meteorite (howardite) from Antarctica. One nicol.

Fig. 6b. The same as Fig. 6a. Nicols crossed. The plagioclase grains are twinned after the pericline (40%), albite (30%) and albite-Carlsbad (30%) laws.

Fig. 7a. Equigranular plagioclase (Or_0 Ab_{11} An_{89}) showing adcumulus texture with pyroxene in eucrite fragment (central and lower parts of this photomicrograph; E-4 in Fig. 3b) of Yamato-7308 meteorite (howardite) from Antarctica. One nicol.

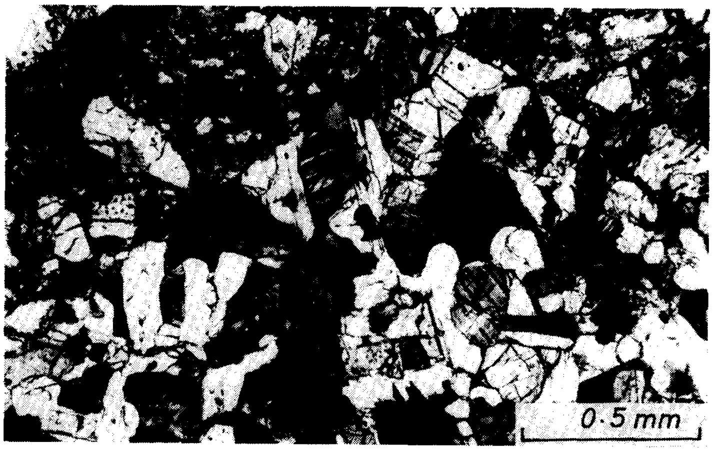

Fig. 7b. The same as Fig. 7a. Nicols crossed. The plagioclase grains are twinned after the albite (45%), pericline (35%) and albite-Carlsbad (20%) laws.

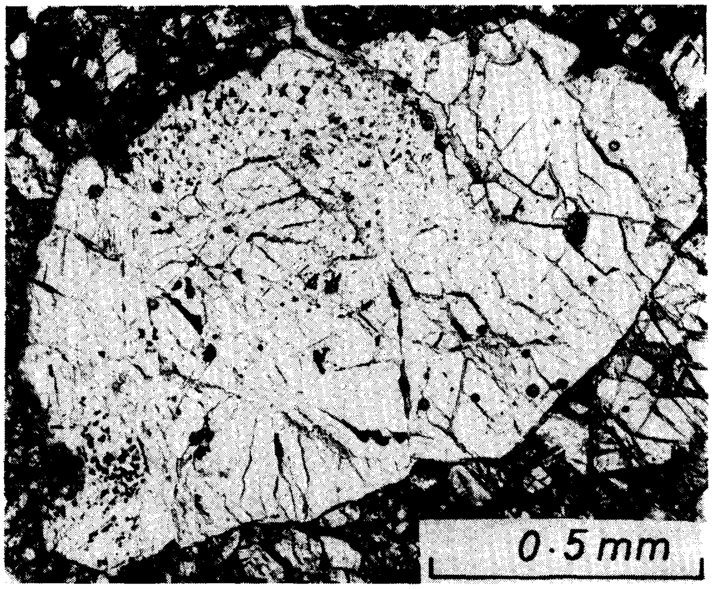

Fig. 8a. Individual plagioclase grain (Or_0 Ab_4 An_{96}) showing clear shadow extinction in matrix (Pl-1 in Fig. 3a) of Yamato-7308 meteorite (howardite) from Antarctica. One nicol.

Fig. 8b. The same as Fig. 8a. Nicols crossed. The plagioclase is twinned after the pericline (75%) and albite (25%) laws.

Fig. 9. Individual plagioclase grain (Or_0 Ab_6 An_{94}) showing clear shadow extinction and kink band in matrix (center of this photomicrograph; Pl-2 in Fig. 3a) of Yamato-7308 meteorite (howardite) from Antarctica. Nicols crossed. The plagioclase is twinned after the pericline law.

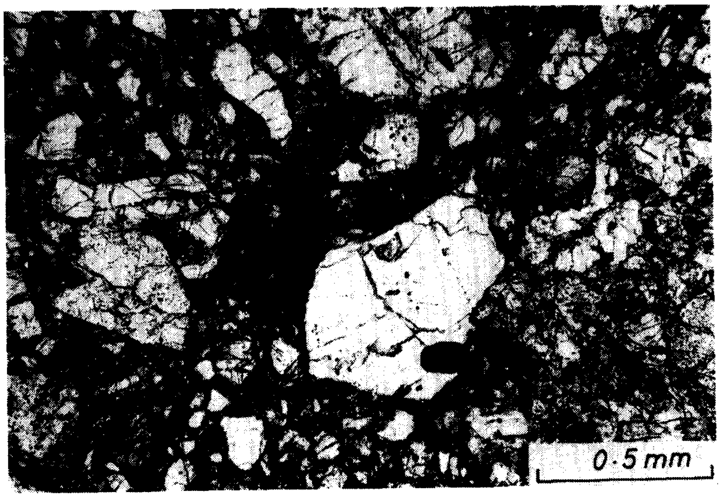

Fig. 10a. Individual plagioclase grain (Or_0 Ab_5 An_{95}) showing no shadow extinction in matrix (center of this photomicrograph; Pl-3 in Fig. 3a) of Yamato-7308 meteorite (howardite) from Antarctica. One nicol.

Fig. 10b. The same as Fig. 10a. Nicols crossed. The plagioclase is twinned after the pericline law.

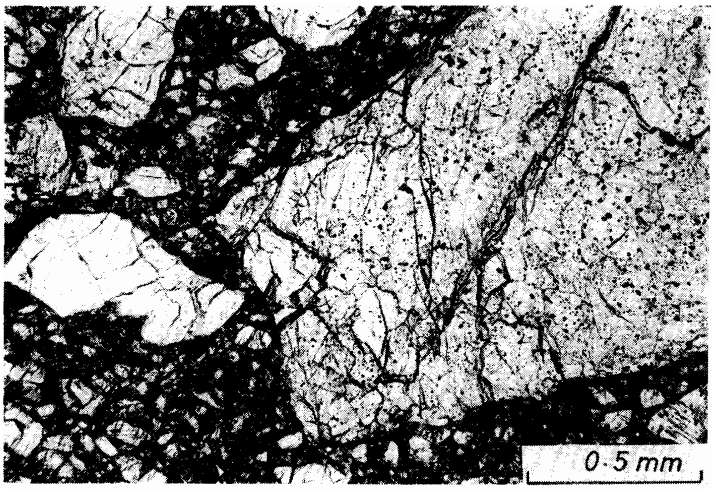

Fig. 11a. Diogenite fragment (central and right parts of this photomicrograph; D-1 in Fig. 3a) and individual plagioclase grain (Or_0 Ab_2 An_{98}) showing no shadow extinction in matrix (left part of this photomicrograph; Pl-4 in Fig. 3a) of Yamato-7308 meteorite (howardite) from Antarctica. One nicol.

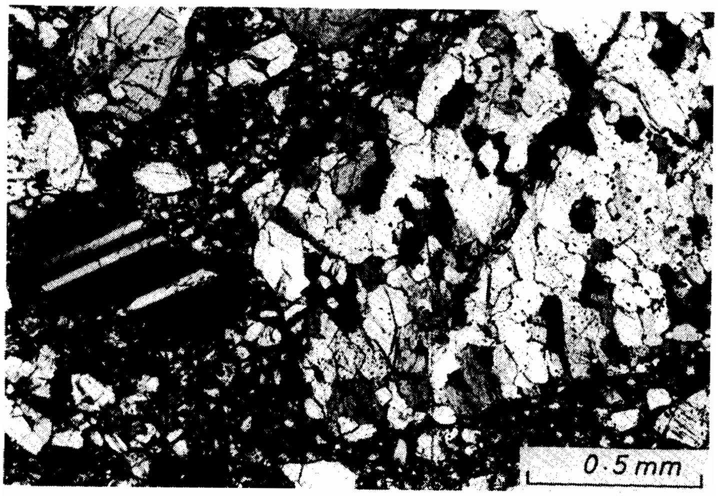

Fig. 11b. The same as Fig. 11a. Nicols crossed. The plagioclase is twinned after the pericline law. This characteristic texture of the diogenite fragment composed of equigranular aggregate of orthopyroxene with low birefringence shows a feature which led to it having been mistaken for anorthosite fragment by YAGI et al. (1978).

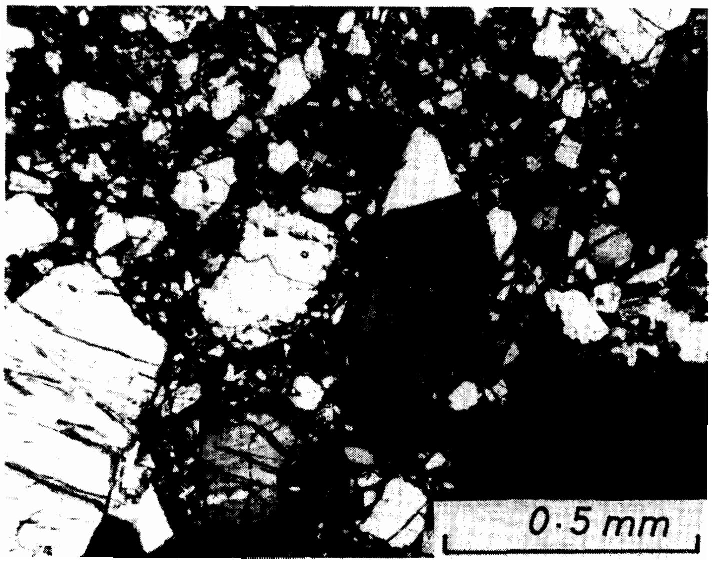

Fig. 12. Individual plagioclase grain ($Or_0Ab_5An_{95}$) showing no shadow extinction in matrix (center of this photomicrograph; Pl-5 in Fig. 3a) of Yamato-7308 meteorite (howardite) from Antarctica. Nicols crossed. The plagioclase is twinned after the pericline law.