A NEW TECHNIQUE TO DETERMINE THREE DIMENSIONAL STRUCTURE OF PORPHYROBLASTS

by

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(with 2 Tables, 2 Text-figures and 3 Plates)

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Abstract

A new technique to establish three dimensional internal structure of a poikiloblastic crystal is proposed in the present article. This is a serial replica method taken from successively scraped and etched surface of a rock specimen attacked by Hydrofluoric Acid. The Cellulose Acetate film is used with Ethyl Acetate as solute. The etching by HF invades only a few microns from the polished surface, therefore, the serial sections are possible to get for every ten microns theoretically. An example applied to a garnet poikiloblast is illustrated and discussed in comparison to the methods already proposed.

This technique is also applicable to many other kinds of poikiloblasts; albite porphyroblast in a spotted schist, "augen" shaped potash feldspar porphyroblast, staurolite poikiloblast and others. This is particularly useful for the study to determine three dimensional texture of fine grained intergrowth textures; reaction rim textures, specific intergrowth and exsolution textures. It is actually possible to distinguish almost all kinds of rock forming minerals, even individual minute grains on the replica, when a microscopic examination of usual thin section is cooperated with. Accordingly, this technique is also useful for the analyses of minor deformation structures; such as minor folds, "augen" structures, fringe and shadow domains, and others in a three

dimensional scale.

Introduction

Types of porphyroblasts of various kinds of minerals are one of the most fascinating subjects in metamorphic petrography. The senior author has been deeply attracted by this subject and had carried out some detailed works on the "augen" shaped potash feldspars (OHTA, 1969) and plagioclase porphyroblasts (OHTA, 1971). On the course of study on the Himalayan geology, the authors found that the garnets in the rocks from this area show very interesting rotated and snowball structures of inclusion trails, indicating apparently two different phases of recrystalization as those described from Scotland (JOHNSON and STEWART, 1963). Before proceeding into any qualitative studies, these garnets were classified based on the structures of inclusion trails, size and morphology, then a difficulty arose on what direction and which position of a crystal is being observed in a randomly cut section. The technique proposed by POWELL (1966) to determine three dimensional trail structure of garnet is only applicable for certain large crystals from which several thin sections of relatively large thickness are obtainable. The present technique is hinted from the serial replica method for the study of fine structures of minor fossils, which has commonly used by paleontologists. Etching is the most delicate technique, but when this has been overcome, the present technique becomes very simple and useful for the study of three dimensional textures of various minerals, especially for the grains of isotropic minerals which do not need care on the internal orientation of a grain. Several sections are obtainable even from a grain of 0.1 mm. in diameter.

The Technique

The technique includes three processes; polishing, etching and replication.

1, Polishing the sample

The sample should be cut in a certain fixed orientation in relation to the cleavage and linear structure of the host rock, then the considerations of the inclusion structures in respect to macroscopic structures become possible. It is convenient to cut the sample normal to the cleavage plane, because the cleavages are mostly exaggerated by phyllosilicate minerals, such as micas and chlorites, which are very easy to be exfoliated away with the replica film.

A tip of rock should be cut into a thin plate thicker than the diameter of certain mineral in question. The size of sample surface is arbitrary, but it is better to take a small one to avoid bubbles during the replication. The outline of surface is better to be taken as a polygon for the determination of a position in replica.

The surface of the sample is polished with polishing powder of #400, #800, #2,000 and #4,000, successively. The first rough polish with #400 essentially determine the thickness regraded away.

The thickness of the sample plate should be measured carefully for the determination of interval distance between successive replicas. A micrometer or a spherometer, a slide calipers for a rough case, can be used. Special care should be taken that the garnet bearing part of a rock is always strongly resistant against polishing and the sample tends to be regraded unevenly.

2, Etching

The polished surface will be attacked by HF acid. A drop of the acid is added on the surface evenly and the sample will be kept some suitable time in a plastic vessel.

The concentration of the HF acid and the time of etching are two important factors of this technique. Some results of preliminary tests for different kinds of minerals are listed in Table 1. Using the thinner acid for longer time etching, more delicate textures are obtainable. The etched sample should be washed carefully by running water.

The etching attacks a few microns of the polished surface. This means that repeated scrap polish is possible for every ten microns theoretically, however, practically possible for every 20 microns or more, for a small grained crystal.

3, Replication

The etched sample is dried and cleaned up in order to avoid the dusts and is kept flatly. A drop of Ethyl Acetate is applied on the surface and a film of Cellulose Acetate of suitable size should be placed above it before the Ethyl Acetate evaporated. To avoid bubbles, the film should be placed from one side of the surface to another very carefully. Keep the sample with the replica film for 5 to 10 minuites until the Ethyl Acetate dries up completely.

Then the film is peeled off from the sample carefully and is placed on a slide glass with a cover glass above. The binding agent is better to choose one which dries quickly within a few minuites. This should not apply on the replica film.

The photographic techniques make them possible to enlarge into any suitable size. The etched pattern printed on the replica film is accurate enough to examine under the microscope with an intermediate magnification. The grain boundaries of same kind of mineral, such as quartz mosaic, are definitely observed when the etching is suitable. The perthitic lamellae of alkali-feldspar are also possible to distinguish clearly.

Preliminary tests for some kinds of minerals

Four examples obtained by the present technique are illustrated in Pls. 1 ~ 4. The test conditions for different minerals are shown in Table 1.

Minerals	HF conc. (%)	Etching time	Host rock and Locality
Albite-Oligoclase	24%	45-60 sec.	spotted chlorite schist, Sanbagawa, Japan
Potash-feldspar	24%	2-3 min.	porphyritic granite, Hida, Japan
Staurolite	24%	4-5 min.	staurolite-garnet-quartz schist, Unatsuki, Japan
Garnet	47%	5-6 min.	Garnet-mica schist, central Nepal Himalayas

The albite porphyroblasts, often develop very well in the low grade crystalline schists of the Sanbagawa metamorphic zone, south-western Japan, are mostly very much poikiloblastic with minor inclusions of quartz, amphibole, chlorite and graphite. The inclusion trails show distinctly curved texture which may show rotation movement during growth, or the helicitic structure remaining earlier folded structures. It is important to know how the three dimensional structure of these inclusion trails are. The constituent minerals of the host rock, i.e., chlorite phyllites and schists, are usually weak against the HF etching, therefore, the concentration of etching liquid and the time of etching should be controlled very carefully. With thin liquid for a relatively long time etching is suitable for these materials.

In the case of potash feldspars, the internal structures are very complicated by various inclusions and exsolution patches. The inclusions, mainly of plagioclases, arrange themselves representing zonal distribution and the individual inclusions show more delicate structures as albite rim and myrmekite texture. These distribution pattern and minor textures of inclusions are easy to distinguish on the replica, even some perthite patches. A soft etching is also powerful in the case of potash feldspars as albite mentioned above. Some distinct zonal structures and twin boundaries of plagioclase grains are also visibly by suitable time of etching. The cleavages make the estimation of crystal orientation possible in some cases.

Staurolite often represents typical sponge-like sieve texture in pelitic schists. This complicated texture is able to be established three dimensionally by the present technique, somewhat long time of etching is suitable for this mineral in a micaceous matrix.

Some other common rocks, such as andesites and diabases are tested by this method. The results show excellent for the study of rock textures, even the matrix textures of volcanic rocks appear very clearly by suitable etching. The replicas obtained by this method are just the same as a thin section observed under the open nicol by usual polarized microscope. Almost all kinds of rock forming minerals are distinguishable on the replica when one knows what kinds of minerals occur in the rock specimen by the study under the microscope.

The whole procedures of the present technique take only 15 – 20 minutes for one replica and need quite common apparatus and reagents, therefore, this is a quick and useful technique for preliminary studies of rock textures.

It is convenient to combine this technique with the thin section preparation then the last surface of sample will be obtained as thin section and many replicas can be taken from the scraping process of the sample. An attention should be paid that the slide glass is easily attacked by HF acid and the balsam is soluble to Ethyl Acetate. The best is to cover the slide glass around the sample by paraphine completely.

Description of a garnet poikiloblast

More than ten garnet samples have been studied by the present technique, but no conclusive or genetic idea has been extracted yet. The simplest example of garnet, apparently unrotated poikiloblast from the charnockite of Madras, India, will be described in detail in this article. Only morphological characteristics of this garnet will be treated here from three dimensional points of view. Even these preliminary studies show that the internal structure of garnet poikiloblast is very complicated and is distinctly different in many points from what has already been reported by many authors (GALWEY & JONES, 1962; POWELL, 1966; SPRY, 1969; WHITTEN, 1966).

The host rock

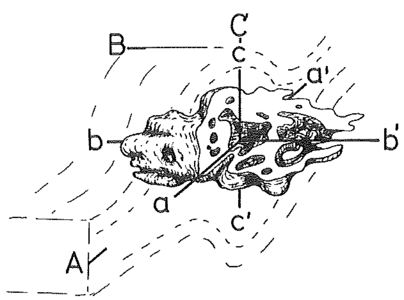
The rock from which the present garnet obtained is a coarse grained garnet-biotite gneiss from the charnockite area of Madras, India. This rock is gneissose, representing weak compositional layering. The main constituent minerals are quartz, plagioclase, potash-feldspar, biotite and garnet, with accessories of graphite, apatite and zircon.

The quartzs and plagioclases consist main part of mosaic matrix, the former are elongated shape with some blocky extinctions, and the latter are of mainly medium grains showing well developed polysynthetic twin lamellae and of An 25–40. Some plagioclases are large porphyroblasts with square-shaped antiperthitic potash-feldspar. A little amount of slightly perthitic orthoclases occur in the matrix as interstitial grains. The biotites are medium to large flakes with X = brown, Z ≑ Y = fresh brown tint. They abut to the garnet and accentuate the gneissose structure with garnet. The garnets are irregular poikiloblasts with many embayments and apparent inclusions. The inclusions are mainly plagioclases with some quartzs and a little amount of biotite. All these inclusions are in rounded outline, especially the quartzs show small projection against the host garnet. The inclusions are apparently composed of two or more grains when they are large, but are single crystal when they are small. Detailed internal structure of a garnet poikiloblast will be described below.

The garnet

The sample is prepared in the direction that the replicas can be taken roughly perpendicular to the B-tectonic axis of the rock. The co-ordinates of the garnet are tentatively taken parallel to the tectonic axes of the host rock as a, b and c (Fig. 1). The serial sections are taken for every 0.15 – 0.2 mm. interval, and the total number of replicas for the present example is 60. Thus, the diameter of this garnet is 6 mm., 9.3 mm. and 5 mm. respectively for the a-, b- and c- axis direction.

1



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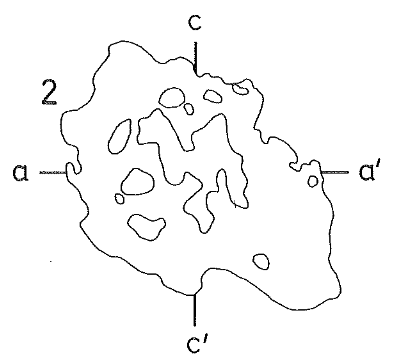
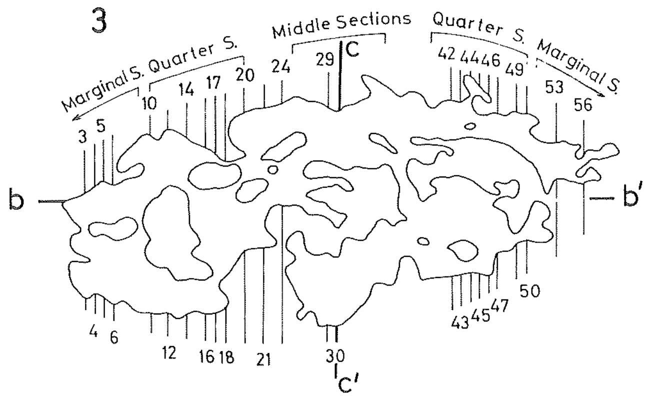
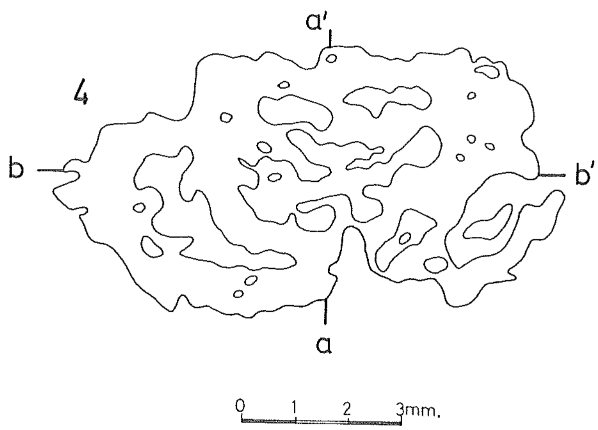






Explanation of the figures

Fig. 1 The garnet poikiloblast.

1, Three dimensional shape of the garnet.
   A, B, C; the tectonic axes of the host rock.
   a, b, c; tentative co-ordinates for the garnet.

2, The a-c section of the garnet. Section No. 30 in Fig. 2.

3, The b-c section of the garnet through the centre. The numbers and their groups correspond to those in Fig. 2 and in the text.

4, The a-b section of the garnet through the centre.

The outline of the garnet grain is very complicated as shown in Fig. 1-1. Roughly speaking, the shape is as an ill-shaped elongated potato decorated by many embayments and tubercular projections on the surface. The outline does not show any apparent symmetry. The traces of outline on the serial sections are mostly very curious amoeba-shape. While in the quarter sections (Nos. 6~20 and Nos. 43~50 in Fig. 2), two sides of the garnet show nearly linear profile, although they are disturbed by many embayments and projections. These linear parts of profiles indicate two pairs of symmetric planes in relation to the b- axis, i.e., the B-tectonic axis, and may or may not represent some crystallographic planes of the garnet. It is noteworthy that such planer outlines appear specially around the quarter sections.

The inclusions within the garnet show many varieties both in size and shape. Four essential types of inclusions are newly proposed here from the three dimensional points of view:

A) True inclusion; completely contained in the host.

B) Incomplete inclusion; the host surrounding is not complete, and at least a small part of inclusion is connected to the matrix outside.

C) Embayment, some large parts of inclusion extend out of the host. In other words, an exotic grain is sticking out the host.

D) Double or triple inclusion; a host mineral occurs within a inclusion grain, and again such host has a inclusion.

The difference between B) and C) type is a comparative classification. They often appear as true inclusion in a section profile.

The areal proportions of different types of inclusions in the present example is shown in Table 2. It is very characteristic that the true inclusions do

Replica No.	Marginal Sections						
	3	4	5	6	10	12	14
Total area (mm^2)	1.99	4.24	5.28	6.44	9.73	11.26	11.77
Garnet (%)	97.30	72.97	83.50	89.73	78.73	70.31	65.56
True incl. (%)	0	0	0	0.33	0	0.38	0.05
Incomplete incl. & Embayment (%)	2.70	27.03	16.50	9.93	19.94	25.97	29.97
Double incl. (%)	0	0	0	0	1.33	3.34	4.43
Total (%)	100.00	100.00	100.00	99.99	100.00	100.00	100.01

Quarter Sections						Middle Sections	
16	17	18	20	22	24	29	30
13.37	13.37	13.16	14.20	16.38	17.65	18.20	17.89
70.37	78.41	77.61	79.41	78.63	75.57	79.53	82.43
0.24	0.04	0	0.04	0	0.03	0	0
29.39	21.55	22.39	20.55	20.85	24.31	20.47	17.57
0	0	0	0	0.53	0.09	0	0
100.00	100.00	100.00	100.00	100.01	100.00	100.00	100.00

	Quarter Sections						
42	43	44	45	46	47	49	50
14.23	14.13	13.67	12.83	12.07	11.23	9.15	7.88
73.97	74.01	79.28	74.48	71.14	66.43	66.73	73.72
0.15	0.34	0.67	0.17	0.13	0.53	0	0
25.88	25.65	20.06	25.36	28.78	31.18	29.69	25.80
0	0	0	0	0	1.87	3.59	0.48
100.00	100.00	100.01	100.02	100.05	100.01	100.01	100.00

Marginal Sections	
53	56
2.06	1.42
91.15	85.23
0	0
8.85	14.77
0	0
100.00	100.00

Averages			
3-6	14-17	28-31	44-47
4.49	11.22	17.84	12.44
85.88	70.81	79.38	72.83
0.08	0.11	0.04	0.38
14.04	27.98	20.59	26.32
0	1.11	0	0.46
100.00	100.01	100.01	100.00

not exceed 1% in any sections. They are always very small grains. The incomplete inclusions are often very large grain, and the connections to the outside matrix are very narrow as B-1 and B-2 in Fig. 2. They are usually the largest in the quarter sections. The embayments develop around the margin of the host garnet as C-1 to C-6 in Fig. 2. It is really noteworthy that the C-4

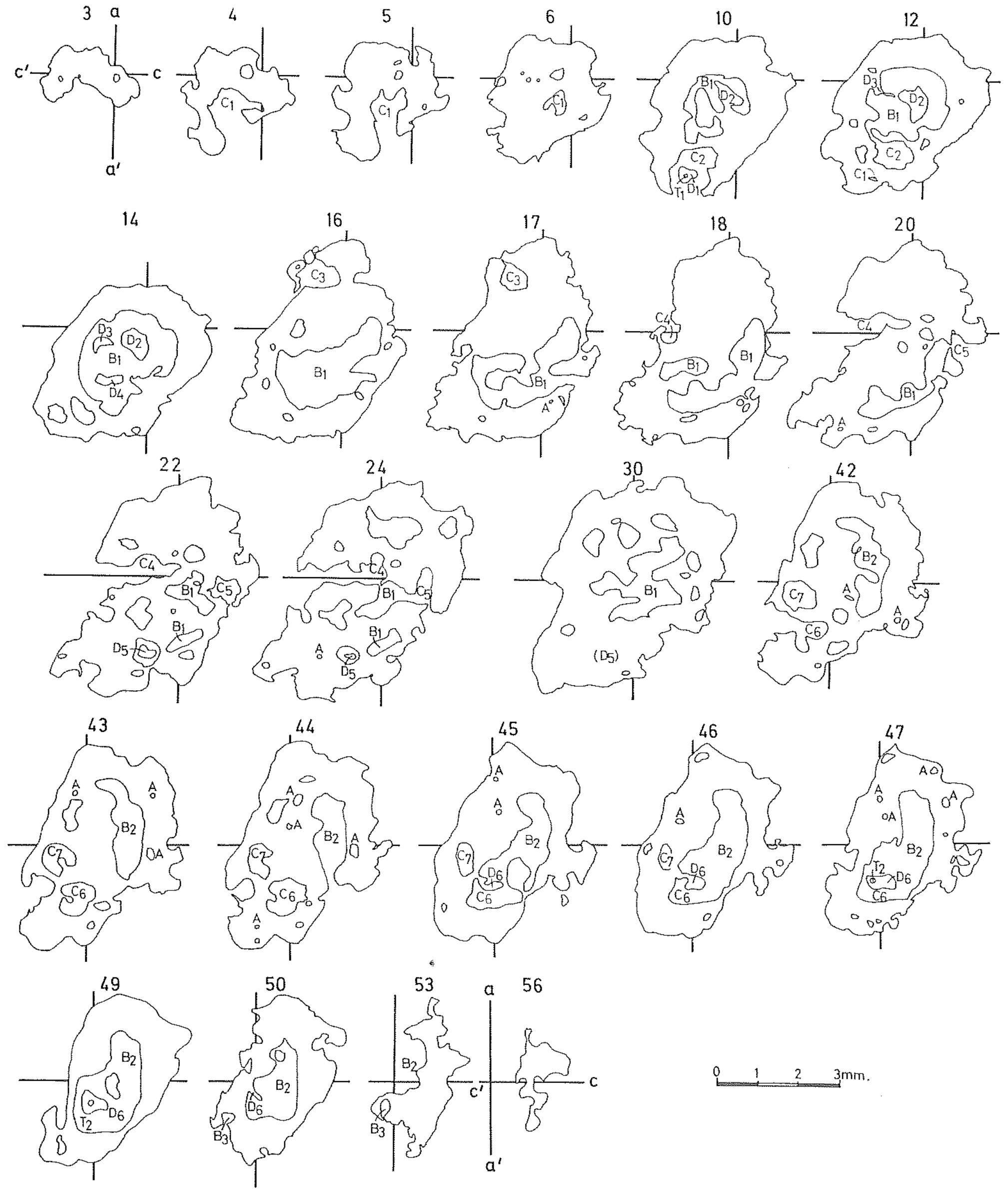


Fig. 2
Serial sections of the garnet parallel to the a-c plane. The numbers correspond to those of Fig. 1. A; true inclusion, B-1 and B-2; typical incomplete inclusions, C-1 to C-6; embayments, D-1 to D-6; double inclusions, T-1 and T-2; triple inclusions. The suffixed numbers indicate the same grain in different sections.

embayment penetrates through the centre of the garnet around the section No. 24 in Fig. 2. These embayments may represent an incident stage of both incomplete and true inclusion.

Double inclusions are sometimes observed in the sections having some large apparent inclusions such as in the quarter sections. The garnet grains apparently contained in the inclusion quartz or feldspar are always connected to the host garnet in the three dimensional space, thus, they are branches of the garnet stretch inside (D-1 to D-6 in Fig. 2).

Triple inclusions appear a few in the sections with large inclusions (T-1 and T-2 in Fig. 2). These double and triple inclusions are often seen in the quarter sections where large incomplete inclusions develop.

Summaries of the description

1). The shape of present garnet is elongated in the b-axis direction; namely in the B-tectonic axis of the host rock.
2). No distinct crystallographic plane is seen, but some planer surfaces occur in the quarter sections, and their symmetry axis is the b.
3). Various inclusions are classified into four types. It is interesting that most of apparent large inclusions are incomplete inclusion and/or embayment, and the true inclusions are very little in amount. Double and triple inclusions are branches stretching inside. An embayment penetrate through the middle part of the garnet.
4). The domains around the quarter sections are specific parts where the amount and size of inclusions are larger than the other parts, and have planar outline.

Even from the present example, two important results have been obtained; the essential classification of inclusions, and surprisingly little amount of true inclusions. Many other new evidences are arising from other examples of apparently rotated garnet, and they will be reported in the successive articles. Much more empirical data on the three dimensional structures of garnet are requested before any geometrical and genetic interpretations will be given for the garnet poikiloblasts.

Acknowledgements

The authors are grateful to Prof. S. HASHIMOTO, Prof. H. KOBAYASHI and Prof. K. KIZAKI for giving them many helpful discussions on the present subject. They are also thankful for the technical advices by Prof. S. UOZUMI, and the improvement of English by Prof. M. KATO. The encouragement and support of Prof. T. ISHIKAWA for this study are gratefully acknowledged.

This research is a part of the Himalayan study by the Scientific Expedition of Nepal Himalayas of Hokkaido University, 1969.

Reference

GALWEY, A.K., and JONES, K.A. (1962); Inclusions in garnet, Nature, vol. 193, p. 471

JOHNSON, M.R.W., and STEWART, F.H. (1963); The British Caledonides, Oliver and Boyd Co., London

OHTA, Y. (1969); On the formation of augen structure, Lithos, vol. 2, No. 2, pp. 109 – 132

OHTA, Y. (1971); Plagioclase porphyroblasts from an amphibolite paleozome, Lithos, vol. 5, pp. 73-88

POWELL, D. (1966); On the preferred crystallographic orientation of garnet in some metamorphic rocks, Miner. Mag., vol. 35, pp. 1094 – 1109

RAST, N. (1965); Nucleation and growth of metamorphic minerals, in Controls of Metamorphism, ed. PITCHER, W., and FLINN, G.W., Oliver and Boyd Co. London

SPRY, A. (1969); Metamorphic textures, Pergamon Press, London

WHITTEN, E.H.T. (1966); Structural geology of folded rocks, Rand McNally and Co., Chicago

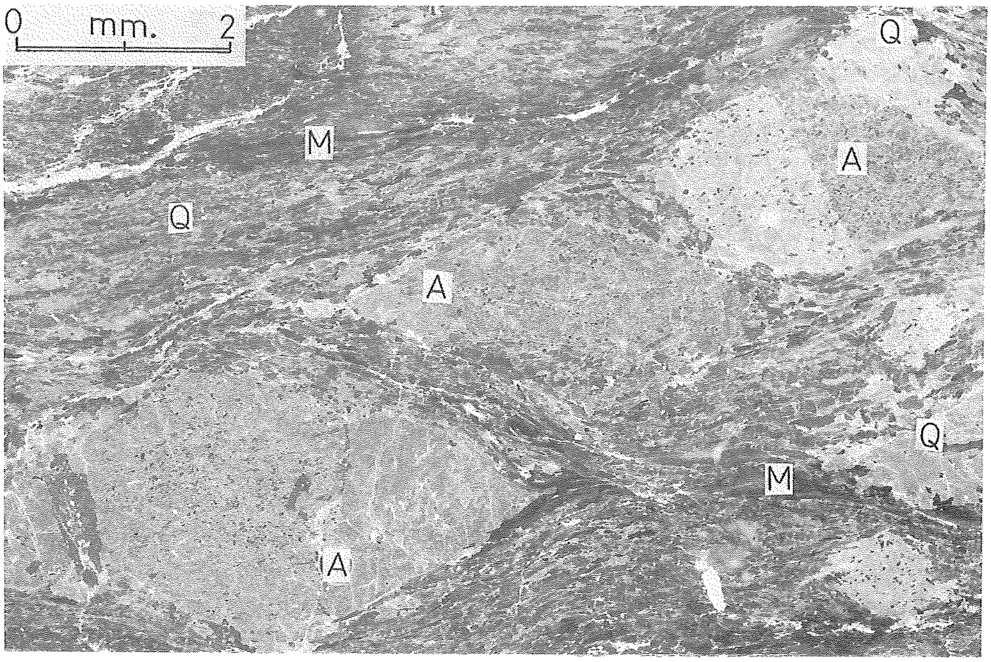
(Manuscript received August 31, 1971)

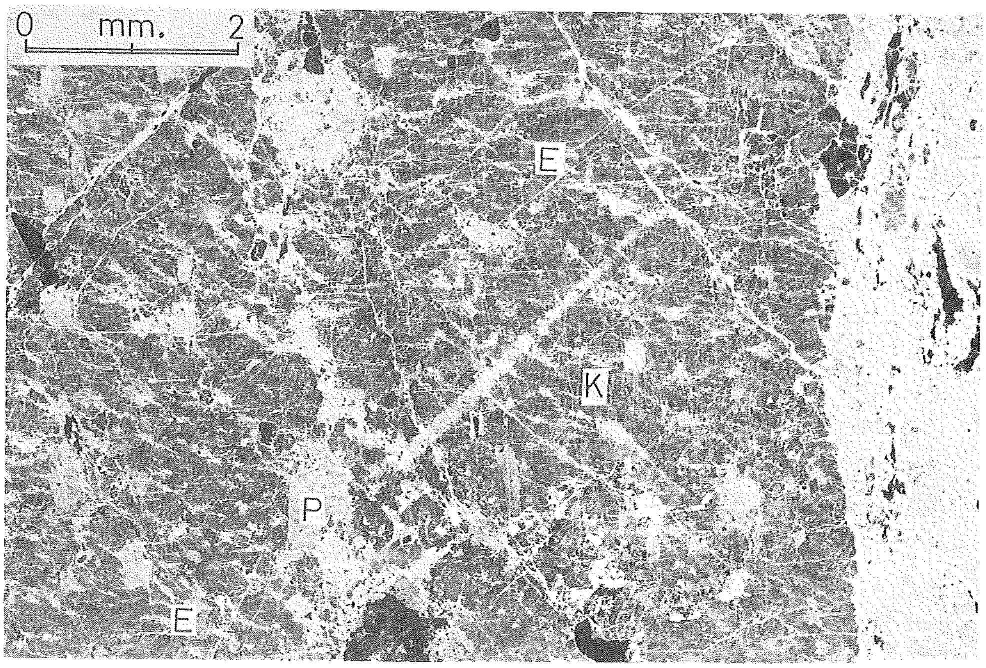
PLATES 1~3 AND EXPLANATION

Explanation of Plate 1

1. Replica photograph of the spotted schist, Sanbagawa metamorphic zone, Nagano prefecture, central Japan. A Carlsbad twin is visible in the albite at right upper corner. A; albite, Q; quartz, M; micas

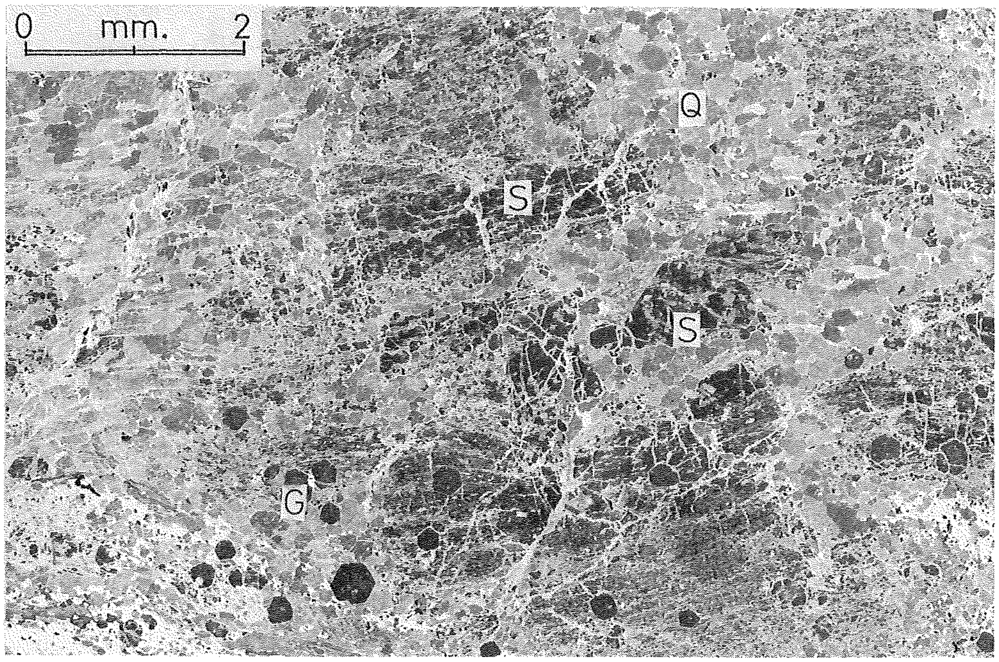
2. Replica photograph of the potash-feldspar from the Funatsu granite, Toyama prefecture, central Japan. K; potash-feldspar, P; plagioclase inclusion, E; perthite patches.

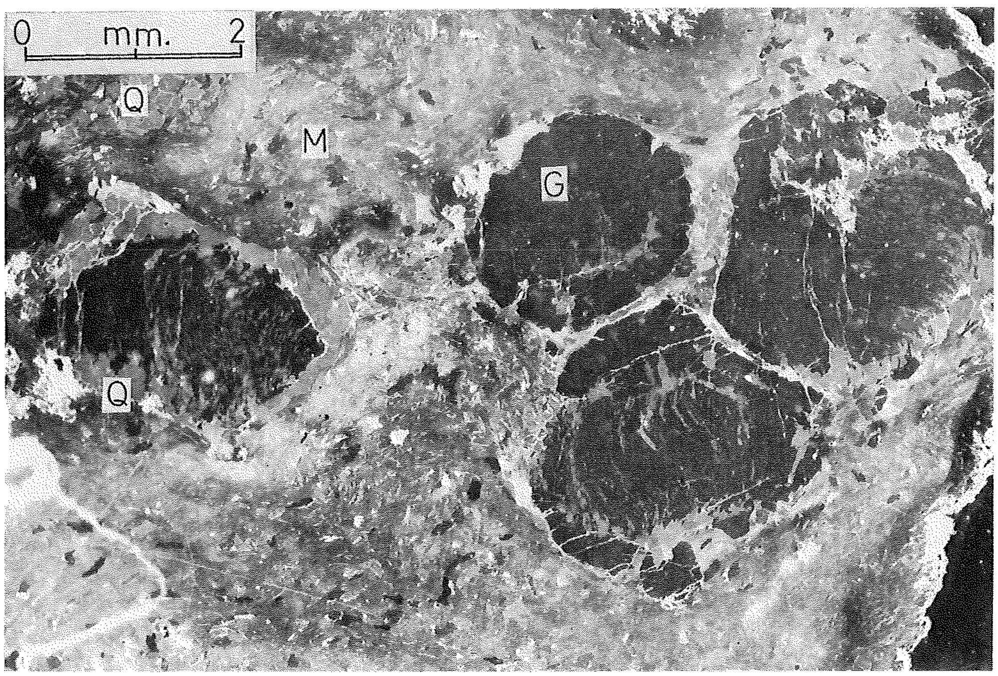

0 mm. 2
M
Q
A
A
Q
M
A
Q


0 mm. 2
E
K
P
E

Explanation of Plate 2

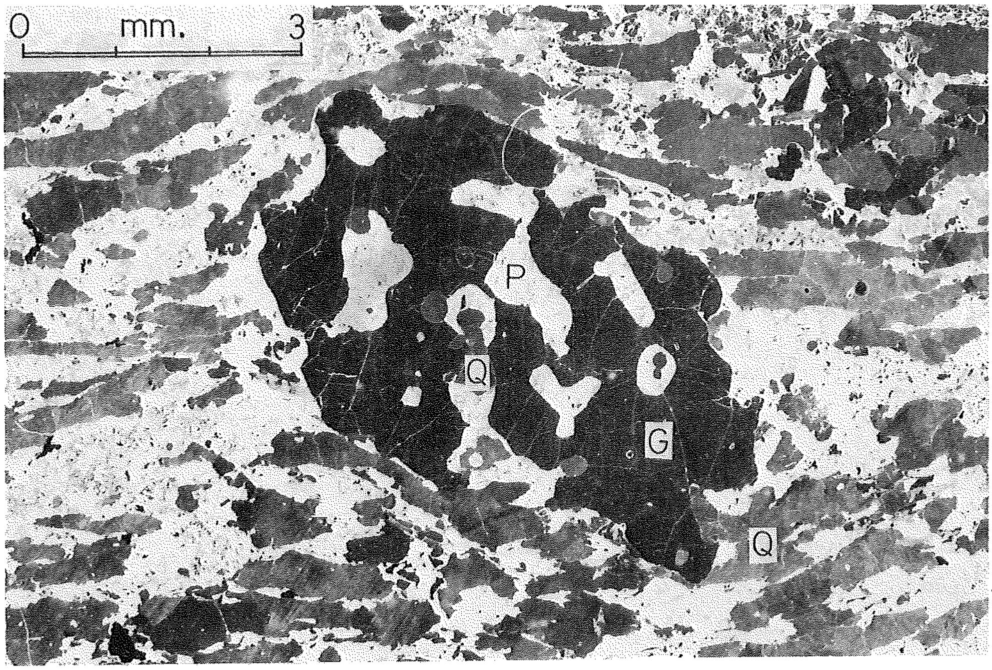
1. Replica photograph of the staurolite-mica schist, Unatsuki, Toyama prefecture, central Japan. S; staurolite, G; garnet, Q; quartz.
2. Replica photograph of the garnet-mica schist, north of Gurkha, central Nepal. Note the S-shaped inclusion trails in the core and the mantle without inclusion. G; garnet, Q; quartz, M; micas.

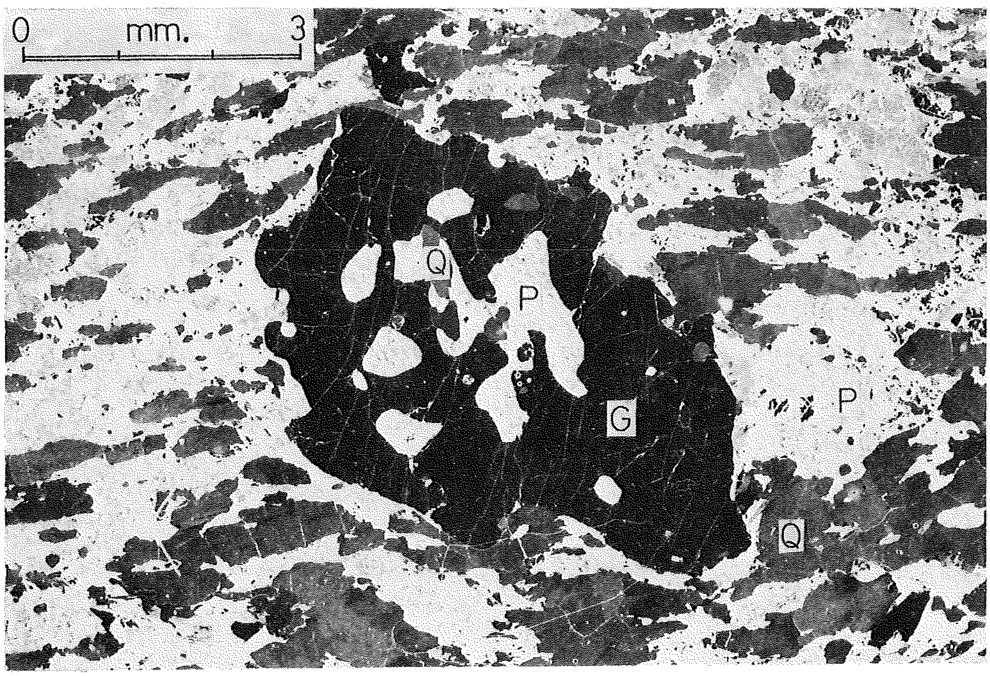

0 mm. 2
Q
S
S
G


0 mm. 2
Q
M
G
Q

Explanation of Plate 3

1. Replica photograph of the garnet described in the present article(refer to Fig. 2). Section No. 24, where the C-4 embayment penetrates through the middle of the grain. G; garnet, P; plagioclase, Q; quartz.
2. Replica photograph of the garnet described in the present article. Section No. 30, around the centre of the grain. G; garnet, P; plagioclase, Q; quartz.


0 mm. 3
P
Q
G
Q


0 mm. 3
Q
P
G
P
Q