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Dedicated to Professor Atsuo Harumoto in Commemoration
of his Retirement on the 16th November of 1959

The Radioactive Accessory Minerals and Their Distribution in Some Granites in Japan

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Abstract

The distribution of the radioactive accessory minerals in some granites in Japan was investigated by the aid of autoradiographic method. Results obtained on specimens from 15 different granitic intrusives indicate that more than 80 percent in volume of the whole radioactive accessory minerals are situated on the boundaries of the major constituent minerals, and also that this trend is more distinct than in the case of the Gyojayama granite reported in the writer's previous paper.

Some petrographic descriptions on the granites and discussions on the manner of distribution of these radioactive accessory minerals were made.

Introduction and Acknowledgement

Radioactive minerals which distribute widely in the earth crust as a part of accessory component in rocks are indeed small in quantity, but the rôle that they play, together with major constituent minerals, in the consolidation of magma or in the later geologic phenomena, may be complicated because of the effects caused by radioactive disintegration.

The experiment carried out with photographic plate for the first time, about 60 years before, concerning radioactive mineral, seems to have surely brought a revolution upon natural science, and in geology, many authors have been interested in the distribution or behaviour of these radioactive minerals or substances, and one can't ignore them in discussing geological problems in these days.

Numerous studies on the radioactivity of the earth crust have been done and the writer thinks that there have been two different standpoints or methods in them. One is mineralogical; by picking up some individual crystals of large size from granite or pegmatite, their chemical compositions are determined, their ages are estimated, or the crystal structures are analysed by X-ray or by other physical methods. The other is the measurement of the whole radioactivity of rocks which is carried out by reducing them to powders or solutions. Thus many authors have contributed much to solving of geological problems.

These methods, however, can't clear up all the questions concerning the radioactivity of the earth crust, e. g. in what state the radioactive elements do occur in rocks, and it seems to be of great importance to clear the positions of the radioactive accessory minerals *in situ,* in other words, the distribution of them in the predominant minerals.

How delicate the measuring instruments may be, they may not be able to distinguish the minute radioactive accessories of several microns in diameter contained in rocks, and in chemical analysis a careful attention must be paid, for instance, to the fact that allanite often contains apatite and sometimes biotite or plagioclase as microscopical inclusions.

In this way, using nuclear emulsion developed in these days, the radioactive accessory minerals in rocks have been investigated[1], and these studies are significant in filling the vacancy of radioactive studies of the earth crust, but so far as these investigations are concerned, they are confined to a partial or special objects and there are few works[2] that clear the relationship between the radioactive accessories and the major constituents, quantitatively.

Here, the present writer examined the thin sections of granite specimens collected from several localities in Japan, and by the aid of nuclear emulsion, the distribution of radioactive accessory minerals in these granites, especially the positions of these minerals in predominant ones, were studied petrographically Moreover, the volume, radioactivity, species of these minerals, and their distribution densities were studied and the results thus obtained in the granites of different localities were compared with each other.

This is an application of the method by which the present writer had examined in the granite of Gyojayama, Kyoto Prefecture[3], and the results obtained here were the same, or moreover the tendency that the radioactive accessories situate on the boundary of major constituent minerals was more distinct than in the granite of Gyojayama. The areas of granitic rocks under consideration are as follows:

1. Hiei area, Kyoto Prefecture
2. Kasagi areas, Kyoto and Nara Prefectures
   a) Kasagi area
   b) Yagiu area
3. Hoki area, Kyoto Prefecture
4. Yono areas, Osaka Prefecture
   a) Kirihata area
   b) Ninjoji area
   c) Tarumi area
   d) Sendaiji area
5. Mihoro area, Gifu Prefecture
6. Taira areas, Fukushima Prefecture
   a) Earlier granite area
   b) Later granite area

7. Karikachi areas, Hokkaido Prefecture
   a) Medium grained area
   b) Fine grained area

These are the granites of various conditions and have been studied petrologically by many authors, but no systematic descriptions on radioactive accessory minerals have been made.

The difference of radioactivity in each granite seems to depend on the degree of erosion, that is to say, whether the granite mass is deeply eroded or not.

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General Remarks on Petrography

1. HIEI GRANITE

This granite exposes in the area of about 24 square kilometers between Mt. Hiei and Mt. Daimonji to the east of Kyoto City, and is regarded as intrusion of Late Mesozoic[4]. Petrological study on this granite is rare[5], but recently an investigation of radium content of this granite was reported by T. ASAYAMA[6].

The rock is medium grained in general, and weathered especially along the mountain peaks. The fresh samples are obtained at the periphery of the exposed mass. Under microscope, quartz varies 19–35% in volume according to different sections, and it is generally transparent and fresh, but often cracks are present in it and are sometimes filled up with brown substances.

Plagioclase mostly belongs to oligoclase, and varies 39–55% in volume by different thin sections, and frequently shows weak zonal structure with basic core, and when decomposed, alters to numerous crystals of minute felsic mineral and sericite.

Alkalifeldspar, 12–35% in volume, mostly shows perthite structure and partially microcline structure, and often occurs as large crystal. Biotite, 4–11% in volume, dark coloured, strong pleochroic (X: brown, Y, Z: dark brown), sometimes shows bended structure, often alters to chlorite, and banded muscovite is enclosed in it. An aggregate of minute biotite is found to and fro. Hornblende is little in amount. As accessory mineral, zircon is often included in biotite with distinct pleochroic haloes, and allanite with weak pleochroism, is mostly situated on the boundary of major constituents above stated, and it rarely includes a crystal of biotite, plagioclase or quartz. Epidote and magnetite are few, apatite is found in all minerals above described, and especially abundant in biotite. The average mode of this rock is given as follows:

quartz	24.11	(in volume)*
alkalifeldspar	20.82	
plagioclase	46.92	
biotite	7.78	
opaque substance	0.18	
accessory mineral	0.19	
allanite	0.0	

2. KASAGI GRANITE

The granite is distributed in the inner zone of Median Dislocation Line, and the area under description is confined to the region surrounded by following points: Kamo, Ogawara (Kansai Line), Oyagiu and Narukawa (northern part of Nara Prefecture). This granite is reported as Early Mesozoic intrusion and is typical facies of so-called "Ryoke type granite". Petrological studies were made by many authors[7].

a) *Kasagi granite*

Samples were collected in the eastern area of Mt. Kasagi along the Kizu river and in the area along the road to Mima village. This rock contacts at the western boundary with hornfels extending north-southern direction, and beyond this hornfels, distributes the Yagiu granite described next.

Constituent minerals are coarse grained, and the average mode is:

quartz	32.50
alkalifeldspar	30.31
plagioclase	32.61
biotite	3.68
hornblende	0.72
opaque substance	0.02
allanite	0.02
muscovite	0.02
other accessory mineral	0.12

Quartz varies 20–42% in volume according to different sections, plagioclase also 20–48%, belongs to oligoclase or andesine and often shows weak zonal structure. Alkalifeldspar sometimes amounts to 58% in volume, and usually shows perthite or microcline structure. Biotite is also large, strongly pleochroic with X: light brown, Y, Z: dark brown or black, and often occurs as a clot of microcrystals of biotite. Furthermore, a small amount of green mica with pleochroism X: light brown, Y, Z: grass green, and chlorite are usually found, and it is considered that biotite alters to green mica and still more to chlorite. A small amount of muscovite is present. Frequently biotite with distinct pleochroism is observed

* The percentage of constituent mineral is given in volume hereafter.

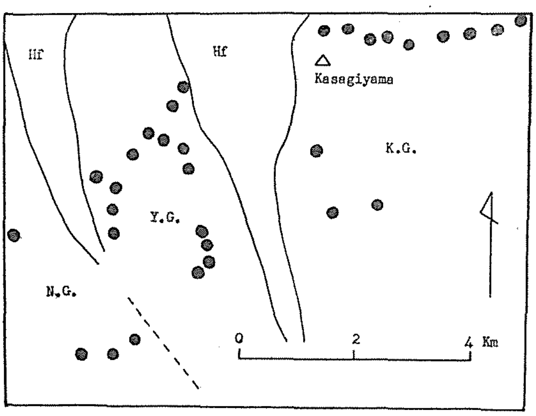

Fig. 1-1. Index map showing the locations of sampling in Kasagi area. Geological boundaries after T. Arita[7].
Hf : Hornfels K.G. : Kasagi granite
Y.G. : Yagiu granite N.G. : Nara granite

filling the interstices of felsic minerals. Green hornblende is found closely connected with biotite and is often large in size with pleochroism X: pale brown, Z: green. Allanite is abundant and often attains to 1 mm long, with strong pleochroism X: pale brown, Z: reddish brown and sometimes contains felsic mineral as inclusion. Apatite, magnetite and zircon are included in above mentioned minerals and the pleochroic haloes are often passed by because of the dark colour of biotite.

b) *Yagiu granite*

It is a fine grained granite, and is regarded as older intrusion. The average mode of constituent minerals obtained from 15 samples is:

quartz	44.05	(20.80–59.35)
alkalifeldspar	7.76	(3.10–13.24)
plagioclase	34.90	(20.84–56.50)
biotite	10.72	(6.97–14.42)
muscovite	1.62	
hornblende	0.52	
opaque substance	0.34	
other accessory mineral	0.19	

The rock is not always homogeneous in texture, and contains microfine part, hornfelsic part or schistose part.

Alkalifeldspar always shows perthite or microcline structure, and plagioclase mostly belongs to andesine and sometime to oligoclase, and weak zonal structure is usually present, and when decomposed alters to the microcrystals of felsic mineral and sericite. Graphic structure is often present. Biotite is lighter coloured than that of Kasagi with X: light brown, Y. Z: brown and they are often arranged in parallel directions with schistose structure. Interstitial biotite between felsics is often seen. A small amount of green hornblende, green mica and muscovite are present and as accessory minerals, zircon which shows distinct pleochroic halo in biotite, and pale coloured allanite with X: pale yellow, Z: pale greenish yellow, are abundantly observed.

c) *Nara granite*

It is a coarse or medium grained granite and resembles to that of Kasagi, and its samples were mainly collected at Oyagiu and Narukawa. Average mode of the samples is given as follows:

quartz	54.97
alkalifeldspar	7.94
plagioclase	28.47
biotite	6.85
hornblende	1.38
opaque substance	0.11
accessory mineral	0.28

Plagioclase belongs to oligoclase, quartz is much in volume, and alkalifeldspar is small in amount and shows microcline structure. Hornblende shows pleochroism with X: pale yellow, Z: green, and biotite, strongly pleochroic with X: pale brown, Y, Z: dark brown. As accessories brown allanite, zircon, magnetite and apatite are usually found.

3. HOKI GRANITE

This granite, medium or fine grained in texture, occurs in the area about 1.5 square kilometers on the road from Kameoka, Kyoto Prefecture to Ikeda, Osaka Prefecture, and contains numerous tiny mafics of green colour so, as a whole, shows rather dioritic appearance. Average mode of this rock is given as follows:

quartz	25.14	(15.90-46.01)
alkalifeldspar	15.56	(4.38-22.20)
plagioclase	47.35	(29.13-56.90)
*biotite	9.59	(7.45-14.90)
hornblende	1.49	(1.28- 6.15)
opaque substance	0.59	
allanite	0.04	
muscovite	0.01	
other accessory mineral	0.23	

(* includes green mica)

Quartz grains are often large and round in form and these parts of this granite show porphyritic texture. In alkalifeldspar perthite structure is usually observed, plagioclase mostly belongs to oligoclase and weak zonal structure with basic core is often present, and when decomposed alters to dirty aggregate of tiny felsics and sericite. The biotite shows strong pleochroism with X: yellow, Y, Z: dark brown. Other constituent minerals are green mica (Y, Z: grass green), muscovite, green hornblende, and as accessories, allanite, apatite, magnetite, titanite and epidote. Pleochroic haloes due to zircon are distinct in biotite. This granite differs from that of Gyojayama in possessing hornblende and allanite in spite of their close localities.

4. YONO GRANITIC ROCKS

Granitic rocks distribute extending about 6 kilometers in length and 5 kilometers in width, in Yono district in the northern region of Osaka Prefecture, and are also reported as Late Mesozoic intrusion. By H. SAEKI, they are classified as follows[8]:

Kirihata pyroxene quartz diorite
Ninjoji quartz diorite
Tarumi amphibole granite porphyry
Sendaiji porphyritic quartz diorite

The first one is peculiar rock type bearing pyroxene, quartz[9] and looks rather melanocratic, and the latter three form the principal part of Yono intrusives composed of medium or fine grained granitic rock.

a) *Kirihata diorite*

The volume percentages of constituent minerals are:

quartz	16.04
alkalifeldspar	1.17
plagioclase	52.88
biotite	8.84
hornblende	13.22
chlorite	3.10
diopside & hypersthene	2.29
opaque substance	1.62
muscovite	0.08
other accessory mineral	0.76

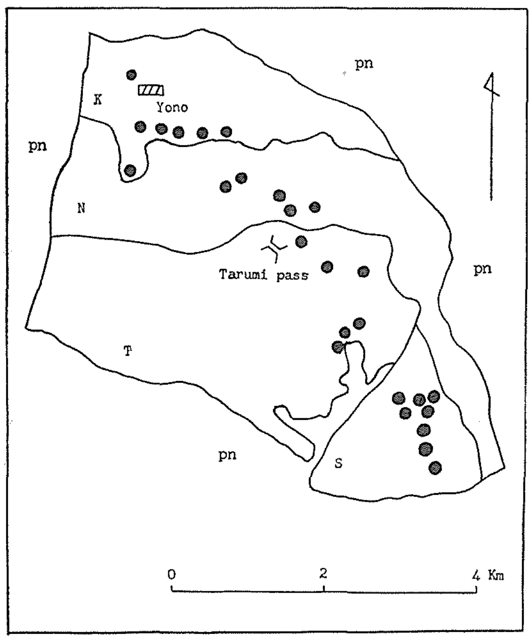

Fig. 1-2. Index map showing the locations of sampling in Yono area. Geological boundaries after H. Saeki[8].
K : Kirihata diorite N: Ninjoji granite
T : Tarumi granite S : Sendaiji granite
pn : Palaeozoic system

As a whole, this rock is medium grained type, abundant in mafic minerals and shows gabbroic appearance. Quartz, alkalifeldspar are little in amount, and felsics are mostly occupied by plagioclase which belongs to andesine or labradorite with An 48%-60%, and graphic structure is often present.

Biotite is pale coloured with X: pale orange, Y, Z: orange brown, and contains less radioactive inclusions than ordinary granite. Green mica and green hornblende are present and the latter is abundant with distinct pleochroism X: light yellow, Z: yellowish green. Diopside, almost colourless or pale green with distinct birefringence, and hypersthene with X: light rose, Y, Z: pale green are found, and they are sometimes large in size.

As accessory minerals chlorite, muscovite, apatite and magnetite are seen, and allanite is not abundant.

b) *Principal granites*

The volume percentages of constituent minerals in each granitic rock obtained from above stated localities are:

	(A)	(B)	(C)
quartz	26.01	34.94	27.89
alkalifeldspar	17.49	17.61	23.27
plagioclase	41.11	38.21	37.22
biotite†	9.15	8.45	9.34
hornblende	3.65	0.05	1.23
chlorite	1.52	—	—
opaque substance	0.69	0.43	0.58
allanite	—	0.06	—
other accessory mineral	0.38‡	0.25	0.47

(A) *Ninjoji area*
(B) *Tarumi area*
(C) *Sendaiji area*
† includes green mica
‡ includes epidote

These three differ from each other in the following points:

	(A)	(B)	(C)
size of grain	medium	fine	fine
texture	equigranular	porphyritic	porphyritic
plagioclase	andesine	oligoclase or andesine	oligoclase or andesine
	weak zonal structure	—	weak zonal structure
	often decomposed	—	often decomposed
green hornblende	present	little or none	little
radioactive accessory	few	abundant	moderate

Common characters found in these three are:
Biotite shows distinct pleochroism with X: light brown, Y, Z: dark brown and partially alters to green mica with pleochroism X: light brown or colourless, Y, Z: grass green. At Ninjoji, clots of minute biotite are often seen. Plagioclase, when decomposed, alters to numerous minute minerals. Alkalifeldspar usually shows perthite structure. Magnetite, apatite and epidote are always present and allanite*, rather pale brown in colour, is abundantly found for accessory. Titanite co-exists with biotite in Sendaiji area. These three rock types seem to be different facies of one granite mass because distinct differences between them cannot be noticed.

* In Tarumi, allanite is distributed more densely than in Hiei or Kasagi.

5. MIHORO GRANITE

This granite is exposed in the area, about 16 kilometers long, along the valley of Mihoro Dam in the western Hida Plateau, Gifu Prefecture, and is reported as Late Mesozoic intrusion. The rock is fine or medium grained, predominant in felsic minerals, and sometimes shows a reddish appearance due to the decomposed potash feldspar. Main part of this granite is distributed between Mihoro and Ushikubi, and in the southern region it borders on quartz porphyry by fault line running east-west direction, and also in the northern margin, gradually alters to the same rock. These areas are now under artificial lake.

Volume percentages of constituent minerals are:

quartz	33.04	(23.50–39.70)
alkalifeldspar	26.30	(12.90–34.01)
plagioclase	36.13	(27.27–53.48)
biotite	3.32	(1.21–7.41)
green hornblende	0.21	
green mica	0.04	
opaque substance	0.59	
titanite	0.10	
allanite	0.07	
other accessory mineral	0.20	

Alkalifeldspar usually shows perthite structure including numerous large patches of albite, and microcline structure including large crystal of plagioclase in the core. These structures are clear and typical in this granite. Plagioclase belongs to albite or oligoclase, often shows weak zonal structure and is usually fresh but sometime alter to decomposed minute minerals. Biotite is little in amount, and has strong pleochroism with X: light brown, Y, Z: dark greenish brown or dark brown. Sometimes it shows a bended structure and alters to green mica (X: light brown, Y, Z: dark green) or further to chlorite.

Magnetite is abundant and occurs in or near biotite, and colourless or smoky zircon with distinct pleochroic halo in biotite, titanite, epidote and apatite are usually found. Hornblende is absent in general but in southern margin, green hornblende occurs frequently, and often includes biotite. Allanite, rather smoky brown in colour (X: light brown, Z: dark brown) is found, and resembles to biotite, but is confirmed by its radioactivity.

Quartz porphyry distributed in this district close-by the above stated granite, is leucocratic rock having large phenocryst of quartz and groundmass composed of minute felsics and a few mafics. Constituent minerals are in the following proportion:

quartz	39.17
alkalifeldspar	43.90
plagioclase	14.20
biotite	1.76
accessory mineral	0.97

Quartz has many cracks in it, alkalifeldspar is abundant in groundmass and usually shows perthite structure. Biotite, pale brown or smoky in colour, often contains opaque substances by decomposition. Green mica, aggregate of muscovite, titanite and magnetite are present and the latter two are abundant for accessory.

6. TAIRA GRANITE

Samples were collected from a part of Abukuma granitic rocks in the area between Shinmachi and Taira, Fukushima Prefecture. Detailed petrological studies were made by "Abukuma Groups"[10,11] to whom the present writer owes for the geological maps.

a) *Earlier granite*

It is a medium or coarse grained granitic rock, but sometimes fine grained xenolithic part containing numerous mafic minerals is found. Average volume percentages of constituent minerals are :

quartz	36.31
alkalifeldspar	17.30
plagioclase	37.18
biotite	7.66
hornblende	0.90
green mica	0.19
opaque substance	0.24
accessory mineral	0.22

Alkalifeldspar usually shows microcline structure and oligoclase is abundant as plagioclase which often shows weak zonal structure. Biotite indicates distinct pleochroism with X : light yellowish brown, Y, Z : dark brown and partially alters to green mica, and then to chlorite. In these mafics, zircon, apatite and magnetite are found and the zircon shows distinct pleochroic haloes. Green hornblende is contained in fine xenolithic part. Allanite, well formed, brown in colour, occurs, but not abundantly compared with other granite.

b) *Later granite*

Average volume percentages of constituent minerals are :

quartz	30.54
alkalifeldspar	19.13
plagioclase	40.35
biotite	8.12
hornblende	1.02
chlorite	0.20
epidote	0.11
opaque substance	0.10
allanite	0.21
other accessory mineral	0.22

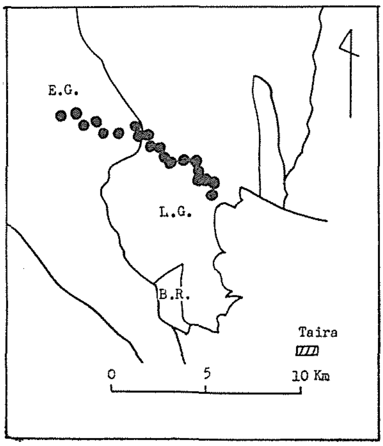

Fig. 1-3. Index map showing the locations of sampling in Taira area. Geological boundaries after Abukuma Group[11].
E.G. : Earlier granite
L.G. : Later granite
B.R. : Basic rock

Alkalifeldspar shows microcline structure. Plagioclase belongs to oligoclase or andesine and also weak zonal structure is observed. Biotite shows distinct pleochroism, mostly with X : light greenish brown, Y, Z : greenish dark brown and rarely X : brownish red, Y, Z : dark red, and green mica shows X : light green, Y, Z : grass green. These three parts of biotite are often observed in one crystal.

Green hornblende is sometimes abundant but sometimes absent, and is often chloritized. As accessories, allanite of brown or greenish brown in colour is abundant, and epidote, zircon and apatite are usually seen.

7. KARIKACHI GRANITE

Granite distributed along the Hidaka mountains, Hokkaido Prefecturc, has been studied by many authors[12] and also regarded as Late Mesozoic intrusion. Samples were collected from the outcrops of Karikachi pass. Two different rock types were distinguished in this granite, one is medium grained granite containing a little alkalifeldspars and pale coloured biotite of bended form. This type occurs in western abrupt slopes neighbouring the Karikachi peaks. The other*, exposed in the eastern slope, is fine grained, leucocratic granite bearing much alkalifeldspar and little amount of dark biotite.

a) *Medium grained granite*

At the western margine in this granite, migmatitic rock is observed contacting with gabbro. On examining the polished specimen of this rock, often molten and complicated structures with many aplitic veins are recognized. Average modes of these granite and migmatite are :

	granite	migmatite
quartz	38.53	28.30
alkalifeldspar	15.73	8.08
plagioclase	33.32	51.20
biotite	11.24	9.49
green mica	0.06	—
chlorite	0.56	2.30
opaque substance	0.35	0.43
other accessory mineral	0.21	0.20

* This is badly outcropped.

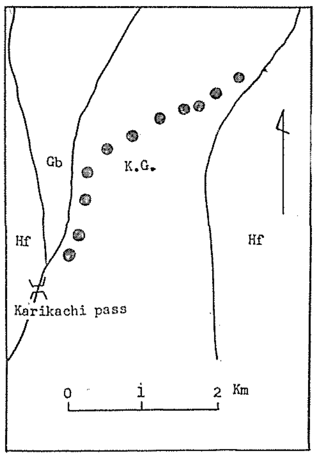

Fig. 1-4. Index map showing the locations of sampling in Karikachi area. Geological boundaries after Hidaka Group[12].

Gb : Gabbro
Hf : Hornfels
K.G. : Karikachi granite

Quartz is rather large and often shows weak undulatory extinction, and alkalifeldspar usually indicates perthite structure and sometimes microcline structure. Plagioclase belongs to oligoclase and often shows dirty feature by decomposition. Graphic structure is observed and generally many cracks are developed in these felsic minerals. Biotite is mostly pale coloured with pleochroism X : light brown, Y, Z : pale brown, and is bended severely and often alters to green mica or chlorite remaining as bended form. Some biotite of reddish brown (Y, Z) in colour shows irregular form filling the interstices between felsic minerals. Moreover, an aggregate of minute biotite (X : gray, Y, Z : grayish green) is found to and fro. Small amount of green hornblende*, and as accessory mineral, zircon with distinct pleochroic halo in mica, magnetite and epidote are met with, but allanite is rare.

b) *Fine grained granite*

This granite is leucocratic containing much alkalifeldspar, less amount of biotite, some allanites as accessory, and is generally homogeneous textured, but sometimes leaves xenolithic part of hornfels origin. Average mode of the samples is given as follows :

quartz	37.88
alkalifeldspar	43.85
plagioclase	14.18
biotite	2.79
hornblende	0.95
opaque substance	0.20
accessory mineral	0.15

This rock is more or less porphyritic in texture, quartz is rather large in size and irregular cracks are developed in it. Alkalifeldspar shows perthite structure but occasionally microcline structure. Plagioclase belongs to oligoclase and is often decomposed and alters to dirty minute minerals. Micrographic structure is seen. Biotite has strong pleochroism with X : light brown, Y, Z : dark brown, and this contrasts well with that of medium grained granite above described. Some biotite fills the interstices between felsics in xenomorphic form. Green hornblende is little in volume but widely occurs (0.07-1.71 percent in volume) and is closely connected with biotite and they often enclose each other as inclusions. As accessories,

* Often includes plagioclase.

magnetite, titanite and epidote are present closely contacting with biotite. Colourless or pale coloured zircon with clear pleochroic halo in biotite, and allanite with X : brown, Z : dark brown or reddish brown are also observed. In a part of this granite which is considered catching hornfelsic rocks, numerous aplitic veins, fibrous actinolitic hornblende, large allanite with reddish colour and zircon are found.

Radioactive Accessory Minerals and Their Distribution in Granite

The distribution of radioactive accessory minerals in the granite samples above described was investigated with nuclear emulsion plate. By exposing the thin section of sample in direct contact with the plate for about a month, the alpha emission pattern produced from minute radioactive accessory minerals was examined. The samples were picked up as widely as possible in order to represent the whole granite mass, and the sampling points were partly illustrated in Fig. 1. A month's exposure is considered to be suitable to detect the radioactivity of ordinary rocks[13] but the exposure was shortened into 6 hours for the most strong mineral in this study.

Radioactivity was expressed, as it had been, by the number of alpha trajectories per unit area per second (T_α). By H. YAGODA, a list of common radioactive minerals found in thin section of rocks is shown as follows[13] :

Radioactive mineral	Colour	$T\alpha$
uraninite	black	215–160
pitchblende	black	186–140
gummite	orange	135
clarkeite	brown	155
curite	orange	134
soddite	yellow	115
thorianite	black	111–76
uranophane	yellow	97–50
torbernite	green	97–82
carnotite	yellow	48–29
autunite	pale yellow	55–40
betafite	brown	29
uranothorite	orange	25–15
ferrothorite	reddish brown	18
samarskite	dark brown	21–15
euxenite	brown	24–16
priorite	black	20– 8
polycrase	brown	12
fergusonite	brown	12
eschynite	black	10
monazite	brown	7– 4
microlite	brown	1.6
allanite	black	0.2–0.8

These accessory minerals* found in this way in each granite sample were partly listed in the Table 1, and the position, colour, size and radioactivity of them were recorded. Here, the size of mineral was expressed by its areas occupied in thin section in the unit of 100 square microns, and the radioactivity was classified into the following grades :

a : very strong
b : strong
c : moderate
d : weak
e : very weak

The species of mineral can't be decided conclusively because these minerals are mostly very small, but those described in the Table are the minerals presumed with much probability judging from the radioactivity and optical characters[14].

1. HIEI AREA

The average number of grains of radioactive accessory mineral obtained in every square centimeter was 2.7** and this is moderate value comparing with other granites after described.

Colourless or pale coloured zircons are abundant and their radioactive intensity is within the range of 0.1–0.2 T_α. When they co-exist with biotite, distinct pleochroic haloes are developed, but they also situate included in or on the boundary of other minerals. Xenotime, monazite and opaque minerals of some strong radioactivity are seen.

Two examples are shown in the Table 1 and besides, following minerals are noticed :

No. of sample***	Situation***	Colour***	Size***	$T\alpha$***	Remarks***
g–31	Pla****	opaque	(3.2)*****	5.70	
g–7	Pla	colourless	(17.4)	0.32	xenotime
g–19	Qtz	colourless	(13.8)	0.75	xenotime
g–42	Pla	smoky	(10.5)	3.40	massive
g–25	Qtz	smoky	(21.0)	0.75	decomposed
g–1	Qtz	colourless	(39 0)	19.10	thorite
g–40	Qtz	colourless	(56.0)	0.94	zircon
”	Qtz	smoky	(13.8)	0.66	zircon
g–53	Alfe	yellow	(8.3)	0.91	zircon

These are indeed contained in one felsic mineral, but are all situated on the fracture or on the center of cracks arranged radially in the host mineral. Large,

* About two thousand grains were examined in this study.
** "Distribution density" will be used.
*** These terms will be abbreviated hereafter and arranged in this order.
**** Pla means the position of mineral included in plagioclase.
***** Expressed in the unit of 100 square microns.

idiomorphic crystal of allanite lies on the boundary of major constituent mineral and shows the value of T_α within the range of 0.3–0.5 and is rarely included in one mineral. In addition to the Table, the following allanites are observed:

g-17	Pla-Alfe*	(700)	0.37	
g-3	Pla-Pla	(530)	0.37	
g-44	Pla-Qtz	(1350)	0.52	
g-53(b)	Bio-Qtz	(410)	0.66	
g-18	Pla-Qtz	(4150)	0.62	
g-43	Pla-Chl	(93)	0.25	
g-27	Qtz-Bio	(255)	0.49	
g-7	Chl-Qtz	(594)	0.43	
g-1	Alfe-Pla	(67)	0.68	
g-26	Qtz-Qtz	(545)	0.29	partly decomposed
g-34	Qtz-Bio-Alfe	(15000)	0.66	
g-31	Pla	(234)	0.35	
g-1	Pla	(167)	0.32	

Strong minerals are few, for example:

g-38	Qtz	brown	(62.2)	26.6	crack
g-34	Pla-Pla	pale brown	(13.8)	63.5	

The former may indicate the value of betafite, and the latter, that of uranophane. In this granite the number percentages of mineral grains classified by their position in which they situate are Bio: 22.4, Pla: 17.6, Bio-Pla: 10.5, Qtz: 7.7, Bio-Qtz: 7.1 (Fig. 2-1), but the percentages of minerals in volume classified again by their position are Qtz-Bio-Alfe: 56.5, Pla-Qtz: 20.7, Pla: 4.5, Bio-Qtz: 3.2, Bio: 1.8**, Qtz: 0.9 (Fig. 2-1).

The relation between the number and the radioactivity of minerals is as follows:

Range of T_α	Percentage in number
less than 1	68
1–2	19
2–3	4
3–4	1.7
4–5	0
5–6	2.3
6–7	0.6

These facts mean that the radioactive accessories enclosed in one mineral are smaller in size than those on the boundary, and a large amount of them are situated on the boundaries of major constituent minerals. In the granite of Hiei, the number of mineral grains with T_α less than 1.0 is most abundant and the number abruptly decreases with the increase of radioactivity (Fig. 3-2).

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* Pla-Alfe means the position on the boundary between plagioclase and alkalifeldspar.

** This value in biotite is far less than that of Gyojayama[3].

2. KASAGI AREA

Distinct differences in radioactivity are recognized between the granites of Kasagi and Yagiu in spite of their close localities.

a) *Kasagi area*

In this granite, distribution density is low ($1.5/cm^2$) and the minerals are weak in radioactivity but are large in size. Most radioactive accessories are allanite and zircon whose T_α are less than 2.0 and when they situate in contact with biotite, pleochroic haloes are observed. As for allanites, they are all large in size, abundantly distributed, and mostly lie on the boundary of major constituents, they were partly shown in the Table 1, and besides, the following cases are noticed:

Kas-2	Pla-Qtz	(100)	0.66	
〃	Bio-Pla	(4200)	0.66	
Kas-8	Bio-Alfe	(425)	0.49	smoky, red brown
〃	Bio-Alfe	(2942)	0.41	
Kas-9	Alfe-Pla	(740)	0.32	
〃	Alfe-Pla	(156)	0.32	
Kas-10	Bio-Alfe	(6600)	0.35	reddish brown
〃	Bio-Bio	(104)	0.48	
〃	Alfe-Alfe	(246)	0.76	
Kas-11	Pla-Pla	(350)	0.27	
〃	Pla	(62)	0.30	
〃	Bio	(75)	0.08	brown
Kas-13	Qtz-Pla	(485)	0.26	includes quartz
Kas-46	Pla-Pla	(226)	0.32	
〃	Pla-Pla	(1025)	0.37	includes apatite
Kas-7	Bio-Pla-Qtz	(1650)	0.075	decomposed*
〃	Bio-Qtz-Alfe	(814)	0.07	decomposed*

Next examples are situated on distinct cracks:

Kas-4	Qtz	opaque	(13.9)	0.26	
Kas-8	Qtz	smoky	(84.0)	0.37	zircon

Even in the case observed to be entirely enclosed in one mineral, many radial fractures are often seen around the grains by photographic observation. Minerals of high radioactivity are few, but the followings are rather strong:

Kas-2	Pla	colourless	(4.2)	7.76
Kas-9	Qtz	smoky	(15.0)	6.90

These correspond to the radioactivity of thorite or ferugsonite. In this granite, the minerals with T_α less than 2.0 occupy about 98 percent in number of all the radioactive accessory grains (Fig. 3-1) and the percentages classified by their positions are as follows (Fig. 2-1):

* Dirty yellowish brown, birefringence weak.

Percentages in number		Percentages in volume	
Bio	22.5	Bio-Alfe	38.2
Bio-Pla	10.5	Bio-Pla	17.3
Bio-Alfe	7.9	Pla-Qtz	10.9
Pla	7.9	Pla-Pla	6.6
Qtz	6.6	Bio-Pla-Qtz	6.2
Alfe	6.6	Pla-Alfe	3.7
Bio-Qtz	6.6	Bio	2.3
		Pla	0.6
		Qtz & Alfe	0.6

This clearly shows that the minerals included in biotite are minute in size and a large amount of them are situated on the boundaries of major constituents.

b) *Yagiu area*

Differences between this granite and above mentioned one, mainly in their radioactive accessory minerals are:

	Kasagi	Yagiu
size of major const. minerals	coarse grained	fine grained
size of radioactive accessories	large	small*
radioactivity of accessories	weak	strong*
distribution density	1.5/cm^2	3.4/cm^2
average area occupied by radioactive accessories per 1 cm^2 in section	474.7/cm^2	176.6/cm^2

This trend is observed also in other granites, that is to say, the radioactive accessories in the coarse grained granite are larger in size, smaller in number and weaker in radioactivity than in the fine grained. The results obtained in this granite are partly shown in the Table, and besides, the following points are noticed: colourless or smoky zircons within 1.2–4.0 T_α are abundant, and especially in the section of sample Yag–59°, Yag–56, Yag–51, Yag–63, Yag–57, Yag–55 are observed zircons situated on veins and cracks developed in quartz or feldspar. Allanite is usually yellowish brown in colour, with weak birefringence, more or less decomposed, and is smaller in size. The following instances are allanites obtained in addition to the Table 1.

Yag–56	Alfe	(1875)	0.48	decomposed
Yag–57	Bio-Qtz	(42)	0.49	decomposed
Yag–61°	Qtz-Hor-Alfe	(1800)	0.49	
"	Bio-Pla-Qtz	(692)	0.52	decomposed
Yag–54	Bio-Qtz	(41)	0.50	
"	Bio-Pla	(8)	0.50	
Yag–62	Bio-Pla	(400)	0.26	
Yag–63	Bio-Qtz	(120)	0.10	

These are mostly on the borders of major constituent minerals, and in sample Yag–51, biotite is observed to have been wrecked by the growth of allanite inclusion.

* These words were relatively usued.

In this granite very strong minerals are present such as:

Yag-56	Bio-Alfe	opaque	(250.0)	61.15	(with brown rim)
Yag-54	Qtz	opaque	(1.9)	155.0	(on crack)
Yag-64	Bio	colourless	(2.6)	12.95	
Yag-58	Bio	colourless	(16.5)	20.0	

In these grains, the former two may indicate the values of thorianite or pitchblende. As a whole, the radioactive accessories are distributed in the major constituent minerals as follows (Fig. 2-1):

Percentage in number		Percentage in volume	
Bio	24.3	Alfe	18.7
Bio-Qtz	14.2	Bio-Pla	17.5
Bio-Pla	13.8	Qtz-Hor-Alfe	16.3
Bio-Alfe	8.7	Pla-Qtz-Bio	8.3
Pla	7.8	Bio-Qtz	8.0
Qtz	6.4	Pla-Qtz	6.7
Alfe	5.0	Bio-Alfe	6.2
Pla-Qtz	3.7	Bio	6.0
Pla-Pla	3.2	Pla-Pla	4.2
Bio-Bio	2.8	Bio-Bio	2.5
		Pla	2.5

The number of mineral grains with T_α less than 1.0 occupies 33 percent of the whole, and with the increase of T_α, the number of percent gradually decreases. This is a marked difference from Kasagi granite (Fig. 3-1).

c) *Nara granite area*

The examined samples of this granite are few, but the general tendency is shown below, and some results were also cited in the Table 1. Distribution density is 2.6/cm², and most of the radioactive accessories are colourless, pale yellow or pale green zircons with distinct pleochroic haloes in biotite, and some are idiomorphic, opaque minerals with T_α 2-3. This granite seems to have an intermediate character in radioactivity between above described two (Fig. 3-1).

The feature of distribution of radioactive accessories is (Fig. 2-2):

Situation	Percentage in number	Percentage in volume
Pla	26.8	14.4
Qtz	17.1	1.9
Bio-Qtz	12.2	71.5
Pla-Qtz	12.0	1.6
Alfe	9.7	2.0
Bio-Pla	7.3	3.3
Bio	4.9	0.9

This fact indicates that a large amount of the radioactive accessories is situated on the borders of major constituents, and the minerals included in biotite are very small both in size and total volume.

3. HOKI AREA

Distribution density is 3.0/cm^2. This granite is rather fine grained in texture, and the radioactive grains are also minute in general. Zircon is abundantly present and pleochroic halo is clear when the mineral co-exists with biotite. Some minerals of strong radioactivity are as follows:

Hok-4	Pla-Bio	pale yellowish brown	(19.2)	11.2
"	Alfe	pale yellow	(2.8)	13.9
Hok-5	Pla	colourless	(3.1)	13.4
"	Alfe-Mag	yellow	(2.1)	23.8
"	Qtz	clourless	(0.8)	10.1
"	Alfe	opaque	(1.4)	11.3
Hok-6	Bio	smoky	(1.4)	11.3

Judging these minerals from their radioactivity and the length of alpha track, they may be thorite or uranothorite class. Allanite of strong pleochroism (Z: dark brown) is always present on the border of the major constituents, with T_α in the range of 0.24–0.54. In this granite the number percentages of grains included in plagioclase, biotite and quartz are 11.4, 11.4 and 3.8 respectively, but in volume, plagioclase: 4.7, biotite: 1.8, and quartz: 0.6, and the majority is on the border of predominant minerals (Fig. 2–2). The number of mineral grains with T_α less than 1.0 occupies 24 percent, T_α 1–2: 28 percent, T_α 2–3: 13 percent, T_α 3–4: 10 percent, and T_α 4–5 is 6 percent (Fig. 3–3). Thus the percentages gradually decrease with the increase of T_α, this trend is seen in the stock type mass as Hoki granite.

4. YONO AREA

Generally allanite and minerals of some high radioactivity are abundantly found especially in Tarumi area, and the distribution densities of each diorite or granite are:

Kirihata	1.8/cm^2
Ninjoji	0.5/cm^2
Tarumi	4.9/cm^2
Sendaiji	2.1/cm^2

a) *Kirihata area*

Zircons of pale green or pale yellowish brown in colour and weak in radioactivity with T_α less than 1.0 are observed in biotite, in green hornblende, or in green mica with pleochroic haloes, but sometimes these radioactive accessories are not clear by the decomposition of the mafic mineral. Allanite is rare but the folwing is large.

Yon-4	Hor-Pla	(1386.0)	0.33

This rock has a curious composition with quartz and hypersthene, but the cases described below show the radioactivity corresponding to euxenite or thorite.

Yon–5	Qtz-Bio-Alfe	pale brown	(124.5)	8.26	low birefr.
”	Bio-Pla-Alfe	pale brown	(22.0)	12.80	
Yon–6	Bio	colourless	(8.8)	9.37	
”	Pla	colourless	(13.8)	10.7	low birefr.

In Yon–3, two minute opaque minerals of strong radioactivity are recognized*, and in Yon–4 green mica containing brown parts shows T_α 0.013 without any inclusions, and these micas are occasionally met with. The volume percentages of the radioactive accessories distributed in the positions of Hor–Pla, Qtz, Bio, Bio–Pla, Chl–Pla are 55.4, 12.6, 10.1, 9.1, and 6.3 respectively, and this fact shows that these radioactive accessories in this granite have a preferential association with biotite to some extent. This depends on the fact that some large crystals of radioactive accessories are included in mafics and that allanite is rare in this granite, but the trend to assemble on boundaries is clearly recognized (Fig. 2–2).

b) *Yono principal granites area*

Tarumi area

In this granite the radioactive accessory minerals are very abundant and some of them show strong radioactivity. They are mostly zircon with distinct pleochroic haloes in biotite, and allanite** with T_α in the range of 0.14–0.54, in average 0.33. Allanite shows pale brown colour and is situated also on the border of major constituents in idiomorphic form, and the cases that allanite is included in one mineral are only five, that is, decomposed Pla: 1, green Mica: 2, and Alfe: 2. Some minerals of strong radioactivity are:

Yon–13	Bio†-Alfe	colourless	(10.5)	19.90	
”	Bio-Pla	colourless	(24.3)	17.85	
”	Bio†-Bio†	opaque	(100.0)	57.12	
Yon–16	Alfe-Bio	pale yellow	(28.2)	13.10	low birefr.
”	Alfe	pale yellow	(52.0)	16.15	low birefr.

These minerals indicate the values corresponding to thorite, thorianite and uranothorite, and further, the followings may belong to uranophane.

Yon–16	Alfe-Mag	colourless	(0.69)	84.0
Yon–14	Bio†-Qtz-Pla	pale brown	(55.0)	41.75

† indicates green mica.

Sendaiji area

Sendaiji granite occurs contacting with the southern margin of Tarumi granite and both of them are of similar types. Radioactive accessories are mostly zircon of pale colour, allanite, monazite and opaque minerals of some high radioactivity with clear pleochroic haloes. Allanite, pale brown in colour is usually on the boundary, sometimes on the crack or interstice filled with brown materials, especially the following allanites are notable:

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* Opaque minerals included in green mica with T_α 49.5–54.5.

** Abundantly found — 37 pcs were examined.

Yon–25	Pla-Qtz	(692)	0.50	includes plagioclase
〃	Pla-Hor	(1230)	0.52	includes feldspar
Yon–21	Qtz-Pla	(385)	0.24	includes biotite

Some strong minerals are:

Yon–25	Pla-Pla	brown	(19.1)	30.50	
Yon–27	Bio-Alfe	yellowish brown	(52.0)	40.10	partially weak birefr.
〃	Bio-Pla	colourless	(2.1)	23.9	

These radioactivities correspond to those of betafite, uranophane, and

Yon–27	Alfe-Alfe	colourless	(1.1)	6.50

lies on the brown vein connected with biotite, and such cases like this are often observed. In this granite, sometimes biotite or decomposed plagioclase of feeble radioactivity is found.

The trends of distribution of the radioactive accessories in both Tarumi and Sendaiji are nearly the same i.e. the grains of the radioactive minerals are abundantly situated on the border of Bio–Pla and decreases the number in the following order in both granites: Bio, Bio–Alfe, Bio–Qtz, Pla, Pla–Qtz, Pla–Pla. But the total volume of the radioactive accessory minerals included in Bio, Alfe, Pla Qtz is only several percent as shown in Fig. 2–3. Then, the total number of grains with T_α less than 1.0 is the greatest and decreases the number as the radioactivity increases in both granites (Fig. 3–2). These facts may indicate that both granites are not of different origin.

Ninjoji area

Distribution density is the lowest and zircons of feeble radioactivity are usually seen, but some of the high valued are notable:

Yon–9	Pla-Pla	colourless	(15.2)	17.7

is situated on the the radial fractures and has the value corresponding to thorite.

Yon–11	Pla-Qtz	pale yellow	(460.0)	23.15
〃	Pla-Pla-Qtz	pale yellow	(167.5)	25.90
Yon–12	Mag-Pla	pale yellow	(350.0)	34.75–40.60

They are subhedral and large minerals with weak birefringence, low refractive indices and have the values of T_α to be uranothorite or uranophane, these are the peculiar minerals in this district. Allanite is rare but in sample of Yon–12, a brown mineral with T_α 1.0 is presumed to be allanite.

Quartz porphyry dike which runs across this area in the direction from north to south was also examined and some zircons with T_α less than 1.0 and brown allanite with T_α 0.20 were found.

5. MIHORO AREA

Distribution density shows the value of 2.7/cm^2 in this granite, pleochroic haloes are not so frequently met with due to less amount of biotite, and the radioactive accessories often co-exist with magnetite which is rather abundant for accessory. Generally, the radioactive accessories, colourless, brown, yellow, dark green, pale yellow and opaque in colour with T_α in the range of 2.0–10.0, are usual and have an inclination to be high in radioactivity. They are mostly situated on the boundaries or fractures of major constituents. In addition to the lists shown in the Table 1 some strong minerals are partly given as follows:

Mih–26	Bio-Pla	brown	(4.0)	7.20	
"	Pla-Pla	colourless	(3.5)	8.26	
Mih–45a	Bio	colourless	(2.7)	15.20	
"	Bio	colourless	(6.7)	10.85	weak birefr.
Mih–45b	Bio	colourless	(2.1)	20.3	

These radioactivities may belong to those of fergusonite or thorite. Allanite with distinct pleochroism (Z: dark brown) is occasionally found, for instance:

Mih–9	Mag-Pla	(565.0)	0.25	
"	Pla-Qtz-Bio	(244.0)	0.62	includes zircons

Sometimes, titanites of weak radioactivity are observed. As a result, the radioactive accessories in this granite are mostly zircons and some minerals of high order corresponding to fergusonite, thorite or euxenite.

The percentages in volume of radioactive accessories classified by their positions are:

Pla-Qtz	26.1
Pla-Mag	21.0
Pla-Qtz-Bio	10.7
Bio-Pla	7.1
Bio-Qtz	6.1
Bio-Alfe	5.0
Pla	3.6
Bio	3.2

And also in this area, as shown above, a large amount of the radioactive accessories are found on the boundary of major constituent minerals (Fig. 2–4).

On examining the relation between the number and the radioactivity of these mineral grains, the number with T_α 2–3 is the largest (Fig. 3–3) and this is a different point compared with other granite.

Quartz porphyry distributed in the southern region contains colourless or pale coloured zircon and reddish brown allanite (Fig. 3–3). They are usually found among the minute felsics in the groundmass. Some were shown in the Table I.

6. TAIRA AREA

a) *Earlier granite area*

Distribution density is 2.7/cm^2, and the minerals are generally weak in radioactivity. Colourless or pale coloured zircons with T_α less than 1.0 are numerous and clear pleochroic haloes are observed.

The followings are remarkable :

Tair–25	Qtz	pale brown	(8.25)	2.50
"	Pla	colourless	(1.28)	2.90
"	Alfe	colourless	(22.0)	2.10

These are zircons included but situate on the cracks in the host mineral.

Tair–33 Pla pale brown (8.82) 0.75 is a zircon situated on the brown veinlet connecting with biotite.

Tair–25 Bio colourless (4.25) 4.36 is idiomorphic zircon in spite of severe bending of biotite.

Tair–28	Alfe-Bio	(457.0)	0.25
"	Alfe	(418.0)	0.35
Tair–33	Qtz-Pla-Mag	(174.0)	0.24
"	Bio-Qtz	(348.0)	0.13

These are hexagonal, or interstitial brown allanites containing reddish patches. Moreover, a few minerals of fergusonite class and biotite of feeble radioactivity are found.

The percentages in number of these mineral grains included in Bio, Pla, Qtz, Alfe are 19.0, 17.5, 3.4, 3.4 respectively, but in volume 8.3, 2.7, 0.4, 17.0 respectively (Fig. 2–4). The number of minerals with T_α less than 1.0 occupies 50 percent and the number gradually decreases with high radioactivity (Fig. 3–2).

b) *Later granite area*

Distribution density is comparatively low (1.7/cm^2), as a whole, the distribution feature resembles to that of Kasagi coarse grained granite. As radioactive accessories, colourless, pale yellow or pale brown zircons with T_α less than 1.0, and brown or pale greenish brown allanites are abundant, as for the latter :

Tair–7	Pla–Epidt	(187)	0.31
"	Pla-Pla	(322)	0.31
"	Pla-Pla	(83)	0.15
Tair–9	Qtz-Bio	(111)	0.21
"	Pla-Bio	(348)	0.57
"	Pla-Mus-Bio	(1800)	0.48
"	Pla	(168)	0.31
Tair–11	Bio-Pla	(2100)	0.33
"	Qtz-Qtz	(501)	0.26
Tair -14	Pla-Pla	(56.5)	0.15
Tair–15	Pla-Qtz	(4250)	0.48
"	Qtz	(755)	0.29
Tair–18	Bio-Pla	(1575)	0.62

These allanites are rather large in size and mostly situate on the boundary of the major constituent minerals except two cases. Black or brown materials of irregular form with T_α 0.57–1.60 are present on the borders or cracks of felsic minerals, and sometimes colourless or yellowish, octahedral xenotimes are observed. Some minerals of high radioactivity are :

Fig. 2 (1–5)
The percentages of the radioactive accessory minerals in different situations.
Abscissa denotes the percentages both in volume and number and ordinate the various situations.

■ percentage in volume
□ percentage in number

Fig. 2–1
(1) Hiei granite
(2) Kasagi granite
(3) Yagiu granite

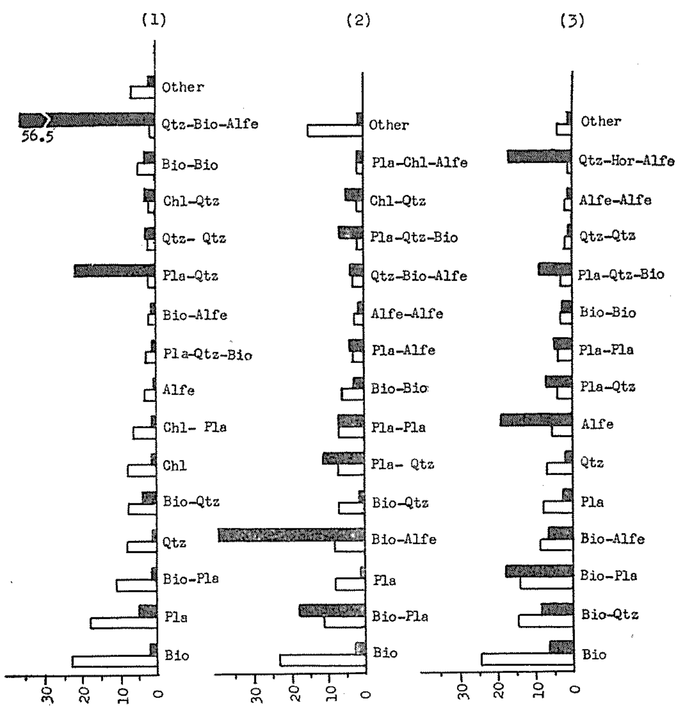
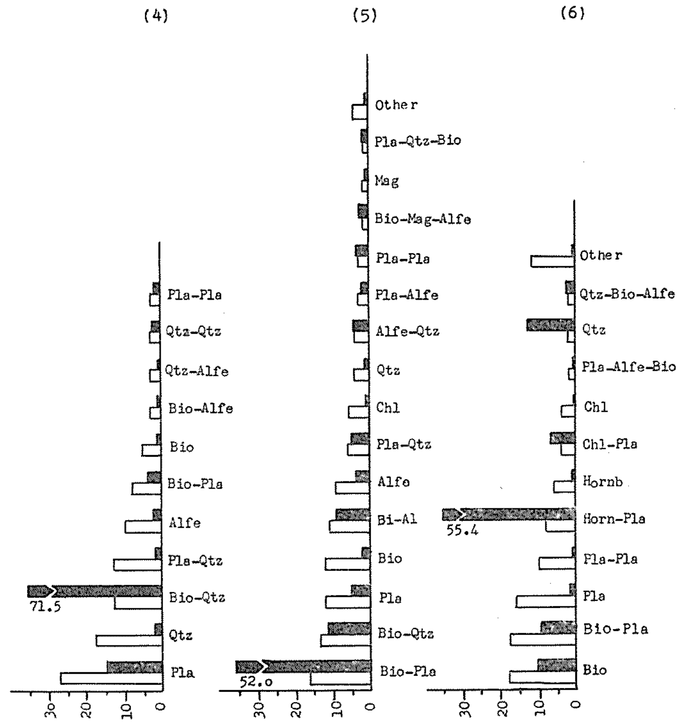


Fig. 2–2
(4) Nara granite
(5) Hoki granite
(6) Kirihata diorite



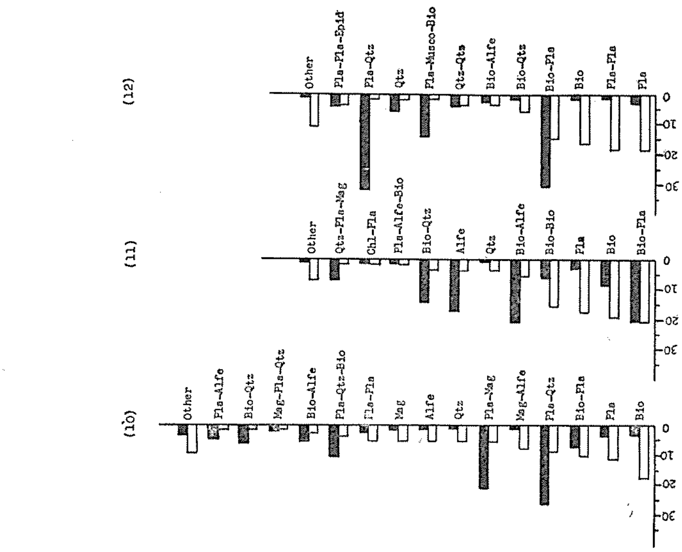


Fig. 2-4
(10) Mihoro granite
(11) Taira (older) granite
(12) Taira (younger) granite

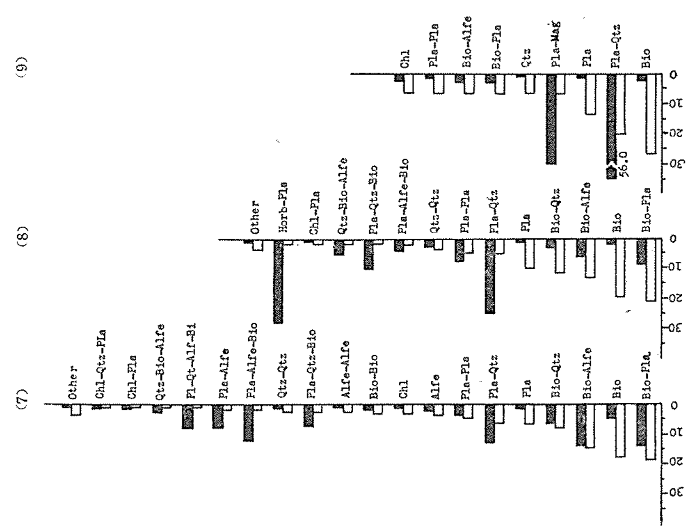


Fig. 2-3
(7) Tarumi granite
(8) Sendaiji granite
(9) Ninjoji granite

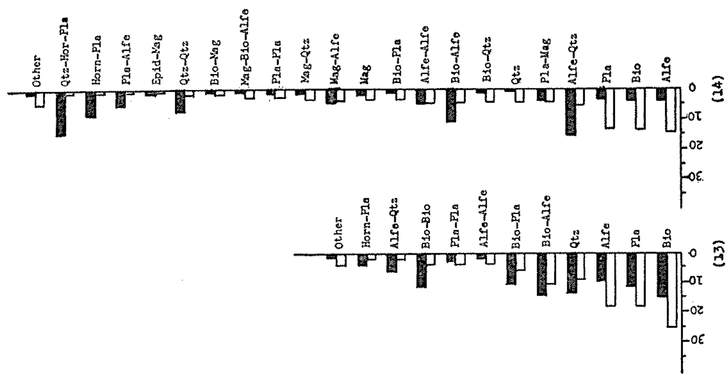


Fig. 2-5
(13) Karikachi (medium) granite
(14) Karikachi (fine) granite

Tair-9	Pla	brown	(5.60)	20.60
Tair-11	Mag	red brown	(21.0)	18.90

these show the value of fergusonite or betafite. Generally speaking, in this granite, the number of mineral grains included in Pla, Bio is comparatively large, but in volume a large amount is situated on the boundaries (Fig. 2-4). As a whole, the radioactivity of accessory minerals in this granite is weak, and the minerals with T_α less than 1.0 occupy 86 percent and the mineral with T_α 3.0-5.0 is not present (Fig. 3-2). This is a peculiar point of batholith type granite.

7. KARIKACHI AREA

Generally, the radioactive accessory minerals are abundant, especially in the eastern fine grained area. These minerals are colourless, pale yellow, pale brown or dark coloured zircons with T_α less than 4.0, and frequently make distinct pleochroic haloes in biotite. Allanite is usually found in eastern area. A part of the examined results were cited in the Table.

a) *Medium grained granite area*

Average distribution density is 3.0/cm^2. In the western margin of this granite, melanocratic migmatite is seen between granite and gabbro, and in these parts the radioactive accessories are also found. Some notable cases in this granite are as follows:

Kar-13	Alfe-Bio	colourless	(24.4)	3.8
〃	Bio	colourless	(4.3)	1.9

These are zircons that not deformed in spite of severe bending of biotite.

Kar-13	Qtz	colourless	(4.4)	0.84	zircon
〃	Qtz-Qtz	colourless	(0.7)	10.3	thorite

These are situated on the distinct cracks or brown veinlet developed in host mineral. Some strong minerals are :

Kar-12	Pla	dark	(7.1)	23.51
Kar-4	Bio	colourless	(5.5)	8.30
„	Bio	colourless	(0.8)	17.60

These radioactivites belong to those of thorite and samarskite. Allanite is rare but a few are found in the migmatite part.

In this granite the volume percentage of radioactive accessories included in biotite is comparatively large, and yet this value is less than 20 percent of the whole (Fig. 2-5), and this is partly due to the absence of allanite that often situates on the boundary. The relation between the number and the radioactivity of grains was also illustrated in Fig. 3-2.

b) *Fine grained granite area*

The average distribution density in this granite is 6.2/cm^2 and is the largest in this study. Generally, colourless zircons are abundant and a small amount of accessories with strong radioactivity are present. In this granite, conspicuous are the following minerals which are all dark in colour, square in form, and these are presumed to be monazite or eschynite.

Kar-6	Bio	pale brown	(8.25)	2.40	
„	Alfe	opaque	(24.4)	2.07	
„	Qtz-Bio	smoky	(19.1)	3.56	
Kar-7	Qtz-Alfe	opaque	(6.25)	2.25	
„	Hor-Alfe	opaque	(5.3)	3.77	
„	Pla	smoky	(10.5)	2.75	
„	Alfe	opaque	(2.7)	2.60	
Kar-10	Qtz	opaque	(6.25)	2.18	crack
Kar-11	Mag-Alfe	dark brown	(10.5)	2.00	
„	Alfe-Qtz	opaque	(1.56)	4.50	

The followings are the minerals of some high valued :

Kar-10	Bio	colourless	(0.7)	7.80
Kar-11	Bio-Alfe	colourless	(0.7)	14.30
„	Bio-Qtz	colourless	(0.6)	7.75
„	Qtz	smoky	(2.0)	6.20

Allanite with strong pleochroism is usually found, and is rather small in size and weak in radioactivity as follows :

Kar-7	Alfe	(294.5)	0.17
”	Alfe	(24.3)	0.20
Kar-8	Qtz-Qtz	(306.0)	0.34
”	Pla-Alfe	(222.0)	0.37
Kar-10	Alfe	(110.0)	0.12
”	Qtz-Alfe	(560.0)	0.28-0.43
Kar-11	Pla-Qtz-Hor	(625.0)	0.27
”	Alfe-Alfe	(137.0)	0.17

In the following case, minerals are present along the distinct veinlet filled with brown substances:

Kar-7	Alfe	colourlesss	(13.28)	0.62	zircon
”	Pla-Pla	dark brown	(38.6)	0.80	zircon

The volume percentages of the radioactive accessory minerals situated in the positions of Alfe-Qtz, Qtz-Hor-Pla, Bio-Alfe, Hor-Pla, Qtz-Qtz are 15.9, 14.4, 11.7, 8.4, and 7.1 respectively, and Bio shows only 4.1 in volume (Fig. 2-5). This fact also clearly indicates that the volume of the radioactive accessories situated on the boundaries of predominant minearal is enormously large.

In this granite the minerals of T_α less than 1.0 amount to 46 percent in number and the percentage of mineral with T_α more than 1.0 gradually decreases with the increase of T_α as shown in Fig. 3-2.

Some Considerations and Discussions on the Distribution of Radioactive Accessory Minerals in Granite

1. THE DISTRIBUTION OF RADIOACTIVE ACCESSORY MINERALS IN GRANITES

The granites, under consideration, are various in localities, mineral compositions and geological ages, but when the relations between the radioactivity and the number of grains of radioactive accessory mineral are examined, these granites can be divided into some types. The percentages in number of mineral grains classified by the value of radioactivity were illustrated in Fig. 3 (1-3). Here abscissa denotes the radioactivity in the range of T_α from 1 to 5, and ordinate the percentage in number of minerals*.

1) A *type*

This is a type in which the percentage in number of mineral grains with T_α less than 1.0, amounts to more than 80, and the number abruptly decreases with the increase of the value of T_α (Parabola type). This type is seen in the granites of Kasagi and Taira (Later), both of which are rather coarse grained and have the lowest values of distribution density. These granites expose in broad areas and are considered to have been eroded deeply.

* The grains with T_α more than 5 were neglected in this diagram as they were few in number and very irregularly distributed.

Explanation of Table

1) 2nd column: Alfe, Bio, Chl, Hor, Mag, Pla and Qtz stand for alkalifeldspar, biotite, chlorite, hornblende, magnetite, plagioclase and quartz. A combination for example Chl-Alfe indicates that the radioactive accessory mineral is situated on the boundary between chlorite and alkalifeldspar, more deeply in the former than in the latter, and a combination for example Bio-Qtz-Mag implies the position among three minerals.
2) 3rd column: Colour of the radioactive accessory mineral.
3) 4th column: The size of mineral is given in the unit of 100 square microns.
4) 5th column: a : $T\alpha > 10.0$
b : $T\alpha <$ 10.0–5.0
c : $T\alpha <$ 5.0–1.0
d : $T\alpha <$ 1.0–0.1
e : $T\alpha < 0.1$
(In some strong cases values of $T\alpha$ are given.)
5) In Remarks are given names of radioactive accessory minerals when identification is possible.

Table 1
Radioactive accessory minerals in granite

Hiei (g–53)

No.	Situation	Colour	Size	Radioactivity ($T\alpha$)	Remarks
1	Alfe	pale yellow	8.3	d	zircon (crack)*
2	Pla (decomp)**	colorless	22.0	d	zircon
3	Pla (decomp)	〃	84.0	d	〃
4	Bio-Bio	〃	21.0	c	〃
5	Qtz	〃	24.0	d	〃
6	Qtz-Qtz	〃	13.8	d	〃
7	Bio-Bio	〃	12.5	d	〃
8	Pla	dirty	—	d	(decomp)
9	Pla	smoky	84.0	c	zircon
10	Bio	colorless	1.2	b (5.50)	
11	Chl	〃	42.0	d	zircon

* Zircon is formed in a conspicuous crack in Alfe.
** decomp=decomposed

Hiei (g–33)

1	Alfe-Alfe	colorless	39.0	d	zircon
2	Bio	〃	—	d	〃
3	Pla-Pla	dirty	62.0	d	〃
4	Bio-Pla	colorless	9.8	c	〃
5	Bio	〃	0.7	c	〃
6	Chl	〃	6.2	d	〃
7	Bio-Pla	〃	31.5	a (21.0)	?
8	Bio-Alfe	〃	120.0	d	zircon
9	Qtz-Qtz	pale yellow	8.2	d	xenotime
10	Qtz-Bio	colorless	8.3	c	zircon
11	Chl-Pla	〃	22.0	d	〃
12	Chl-Pla	〃	24.5	d	〃
13	Chl	〃	—	d	minute zircons
14	Bio	〃	12.8	d	zircons(5pcs)

Kasagi (Kas–12)

No	Situation	Colour	Size	Radioactivity (Tα)	Remarks
1	Pla-Chl-Alfe	red. brown	970.0	d	allanite
2	Chl-Alfe	"	312.0	d	"
3	Qtz-Chl	"	1162.0	d	"
4	Bio	opaque	—	d	(decomp)
5	Pla	colorless	10.5	d	zircon
6	Pla-Bio	"	28.1	d	"
7	Pla-Qtz	"	35.6	d	"
Kasagi (Kas–8)					
1	Qtz	colorless(dirty)	84.0	d	zircon
2	Bio	colorless	26.0	d	zircon (2 pcs)
3	Bio-Qtz	"	16.0	d	zircon
4	Pla	yellow	24.4	c	"
5	Bio	colorless	34.8	d	
6	Bio-Alfe	dirty	2942.0	d	allanite (decomp)
7	Bio-Alfe	red. brown	425.0	d	allanite (decomp)
Yagiu (Yag–51)					
1	Alfe-Bio	pale yellow	125.0	d	allanite
2	Bio-Bio	"	24.7	d	"
3	Bio-Pla	colorless	1.4	d	zircon
4	Bio-Bio-Pla	yellow	22.1	d	allanite
5	Qtz-Pla-Bio	pale yellow	125.0	d	"
6	Pla-Bio	"	725.0	d	"
7	Pla-Bio	"	16.5	d	"
8	Pla	opaque	2.8	c	(massive)
9	Qtz-Bio-Pla	pale yellow	38.3	d	allanite
10	Qtz-Bio-Pla	"	49.2	d	"
11	Pla-Qtz	yellow	41.5	d	(massive)
12	Bio-Alfe	"	54.0	d	allanite
13	Alfe-Bio	colorless	3.5	c	zircon
14	Pla-Bio	"	5.5	c	"
15	Alfe-Bio	yellow	55.6	d	(decomp)
16	Pla-Qtz	"	41.5	d	"
17	Pla-Pla	colorless	6.2	c	(black rim)
Yagiu (Yag–52)					
1	Qtz-Bio	colorless	41.5	d	zircon
2	Bio	"	14.5	d	"
3	Bio	"	21.0	d	"
4	Bio	"	31.5	d	"
5	Bio-Bio	"	4.2	d	"
6	Bio-Bio	"	10.5	d	"
7	Pla-Bio	"	67.2	c	"
8	Bio-Qtz	"	10.5	d	"
9	Bio-Qtz	"	31.2	d	"
10	Bio	"	4.2	d	"
11	Bio	"	10.9	d	"
12	Bio	"	10.0	d	"
13	Bio	"	2.8	c	"
14	Bio	"	22.0	d	"
15	Bio-Qtz	"	6.3	d	"
16	Bio-Qtz	"	7.0	d	"
17	Bio-Pla	colorless(dirty)	29.0	c	"

Nara (Nar-66)

No	Situation	Colour	Size	Radioactivity (Tα)	Remarks
1	Bio	colorless	14.0	c	zircon
2	Qtz-Bio	"	18.5	c	zircon(weak birefr)
3	Pla	"	0.7	b (9.20)	(strong birefr)
4	Pla-Pla	brown	69.0	d	allanite
5	Qtz	pale yellow	8.2	c	zircon
6	Qtz-Bio	colorless	2.7	c	"
7	Pla	"	4.0	c	"
8	Pla-Bio	"	11.0	c	"
9	Qtz	"	6.9	d	"
10	Qtz-Bio	"	11.0	c	(massive)
11	Qtz	pale yellow	6.1	d	zircon
12	Alfe-Bio	colorless	1.4	c	"
13	Pla	"	2.2	c	"
14	Bio-Qtz	"	6.3	c	"
15	Pla	dirty	—	c	(decomp)
16	Pla	colorless	2.7	c	zircon
17	Pla	"	0.4	a (10.60)	(high birefr)
18	Pla	"	—	d	?

Hoki (Hok-4)

1	Pla	pale brown	10.5	d	zircon
2	Mag	colorless	10.9	d	"
3	Bio-Pla	pale brown	8.2	c	monazite
4	Pla-Bio	yellow brown	19.2	a (11.20)	
5	Bio-Alfe	brown	7.0	c	zircon
6	Bio	dirty	—	d	?
7	Bio	"	—	d	?
8	Bio-Qtz	brown	6.2	c	monazite
9	Bio-Qtz	colorless	10.5	d	zircon
10	Bio-Qtz	brown	13.9	c	monazite
11	Bio	"	4.2	c	"
12	Alfe	pale yellow	4.2	c	zircon
13	Pla-Bio	colorless	13.5	c	"
14	Alfe	pale yellow	2.8	a (13.9)	
15	Alfe-Bio	colorless	53.4	d	zircon
16	Bio	opaque	—	c	
17	Pla-Bio	dark brown	730.0	d	allanite

Kirihata (Yon-5)

1	Qtz-Bio-Alfe	pale green. brown	124.5	b (8.26)	(low birefr)
2	Chl	pale green	3.5	c	zircon
3	Bio	colorless	21.0	c	"
4	Bio-Pla-Alfe	pale brown	22.0	a (12.8)	
5	Pla-Bio	"	10.2	d	zircon
6	Bio-Pla	"	8.2	c	"
7	Bio-Pla	"	8.0	c	"
8	Pla-Bio(green)	opaque	153.0	c	(massive)
9	Pla-Chl	brown	17.2	d	zircon
10	Fel-Pla	dark	6.2	c	(massive)

Tarumi (Yon-13)

No	Situation	Colour	Size	Radioactivity (Tα)	Remarks
1	Pla-Qtz	pale brown	61.0	d	allanite
2	Chl-Alfe	"	103.7	d	"
3	Chl	colorless	13.8	d	zircon
4	Chl	"	7.0	c	"
5	Bio-Alfe	pale brown	167.0	d	allanite
6	Alfe	"	55.5	d	"
7	Bio-Alfe	colorless	10.5	a (19.9)	
8	Qtz-Bio-Alfe	pale brown	187.5	d	allanite
9	Pla-Pla	"	235.5	d	allanite (2)
10	Chl-Alfe	colorless	5.5	c	zircon
11	Bio-Alfe-Pla	pale brown	732.0	d	allanite (zonal)
12	Bio (green)	"	6.2	c	monazite
13	Alfe-Bio	"	520.0	d	allanite
14	Chl	colorless	2.8	b	(monazite)
15	Alfe-Pla	pale brown	495.0	d	allanite
16	Pla-Qtz	"	147.0	d	"
17	Alfe-Alfe	"	65.0	d	"
18	Qtz-Bio	colorless	8.3	c	zircon
19	Bio-Bio	"	18.7	c	"
20	Bio-Pla	"	2.1	c	"
21	Bio (green)	"	8.2	c	"
22	Bio (green)	"	6.2	c	"
23	Bio-Alfe	opaque	21.0	d	
24	Bio-Alfe	"	89.5	d	
25	Bio	colorless	4.1	c	zircon
26	Bio (green)	pale brown	114.0	d	allanite
27	Bio-Pla	colorless	4.2	c	zircon
28	Bio-Pla	"	24.3	a (17.85)	
29	Bio-Pla	"	10.9	b	zircon
30	Alfe-Bio	"	2.1	c	"
31	Bio-Bio (green)	opaque	100.0	a (57.12)	(massive)
32	Pla	colorless	6.2	d	zircon
33	Pla-Pla	"	2.1	c	"
34	Qtz	"	2.8	c	"

Tarumi (Yon-16)

1	Alfe-Bio	pale yellow	28.2	a (13.1)	(metamictized)
2	Alfe-Alfe	brown	10.5	c	allanite
3	Bio-Qtz	pale brown	135.0	d	"
4	Bio-Pla	colorless	3.5	c	zircon
5	Bio-Alfe	"	4.1	d	"
6	Qtz-Bio	"	8.4	d	"
7	Pla	pale brown	8.3	c	(massive)
8	Pla	colorless	2.1	c	
9	Pla-Alfe	pale brown	177.0	d	allanite
10	Pla-Alfe-Bio	"	292.0	d	"
11	Alfe-Mag	colorless	0.7	a (84.0)	
12	Alfe (crack)	opaque	20.8	c	(massive)
13	Bio	colorless	4.4	c	zircon
14	Pla-Bio	pale brown	97.0	d	allanite
15	Pla-Bio (green)	"	625.0	d	"
16	Alfe	pale yellow	52.0	a (16.15)	(metamictized)

Sendaiji (Yon–21)

No	Situation	Colour	Size	Radioactivity ($T\alpha$)	Remarks
1	Qtz-Qtz	brown	99.0	d	allanite
2	Bio-Qtz	colorless	10.5	d	zircon
3	Alfe-Bio-Pla	brown	169.0	d	allanite
4	Bio-Pla	colorless	37.5	d	zircon
5	Qtz-Alfe-Bio	brown	225.0	d	allanite
6	Qtz-Pla	"	385.0	d	allanite*

* includes biotite

Ninjoji (Yon–11)

No	Situation	Colour	Size	Radioactivity ($T\alpha$)	Remarks
1	Pla-Qtz	pale yellow	460.0	a (23.15)	
2	Pla-Pla-Qtz	"	167.5	a (25.90)	
3	Pla	colorless	2.0	c	zircon
4	Bio	smoky	5.6	d	"
5	Chl	colorless	32.0	d	"

Ninjoji (Yon–12)

No	Situation	Colour	Size	Radioactivity ($T\alpha$)	Remarks
1	Bio	colorless	7.3	d	zircon
2	Bio-Pla	"	34.9	d	"
3	Mag-Pla	pale yellow	350.0	a (34.7, 40.6)	(2 pcs)
4	Qtz	opaque	1.4	c	
5	Pla	brown	14.5	d	(allanite)

Mihoro (Mih–9)

No	Situation	Colour	Size	Radioactivity ($T\alpha$)	Remarks
1	Mag-Pla	brown (dirty)	565.0	d	allanite
2	Qtz	dark green	8.2	a (11.80)	
3	Pla-Qtz-Bio	brown	244.0	d	allanite (inclndes zircons)
4	Qtz-Alfe	colorless	2.1	a (12.60)	?
5	Mag-Pla	smoky	10.5	b (8.26)	?
6	Pla	colorless	1.5	a (10.32)	?
7	Alfe	"	11.0	b (8.40)	?
8	Mag	"	5.5	c	zircon

Mihoro (Mih–12)

No	Situation	Colour	Size	Radioactivity ($T\alpha$)	Remarks
1	Mag-Alfe	smoky	16.5	c	zircon
2	Mag-Alfe	"	8.2	c	"
3	Mag-Alfe	colorless	2.1	c	"
4	Alfe-Bio	smoky	106.0	c	zircon (low birefr)
5	Bio-Qtz	pale green	125.0	d	zircon
6	Alfe-Mag	colorless	4.2	b	zircon (low birefr)
7	Bio	"	1.6	b	zircon
8	Chl	"	6.2	c	"
9	Mag-Pla	"	13.8	c	"
10	Bio	"	2.8	c	"
11	Bio	"	29.5	c	zircon (2 pcs)
12	Bio-Pla	"	16.0	c	zircon (2 pcs)
13	Mag	smoky	34.8	b (7.30)	

Mihoro (Mih-54) (Quartz porphyry)

No	Situation	Colour	Size	Radioactivity (Tα)	Remarks
1	Bio-Alfe	brown	125.0	d	allanite
2	Pla-Qtz	colorless	4.3	a (10.7)	
3	Bio	brown	13.8	c	zircon
4	Pla	colorless	1.6	a	(low birefr)
5	Bio	dirty	—	d	(decomp)
6	Bio	"	—	d	(")

Taira (Tair-33) (Earlier granite)

No	Situation	Colour	Size	Radioactivity (Tα)	Remarks
1	Qtz-Pla	colorless	10.5	c	zircon
2	Qtz-Pla-Mag	yellow & red	174.0	d	allanite
3	Qtz-Qtz	brown	—	e	biotite
4	Pla-Bio	pale yellow	48.0	c	zircon
5	Bio-Bio	colorless	21.0	d	zircon (metamict)
6	Bio	"	10.5	d	zircon
7	Bio	"	6.2	d	"
8	Bio	"	10.5	d	"
9	Pla	pale brown	8.8	d	"
10	Bio-Bio (green)	"	24.3	d	"
11	Pla-Alfe-Bio	colorless	27.3	c	"
12	Bio-Pla	"	24.3	c	"
13	Bio-Qtz	red brown	348.0	d	allanite (massive)
14	Bio-Pla	colorless	165.0	c	zircon

Taira (Tair-28) (Earlier granite)

No	Situation	Colour	Size	Radioactivity (Tα)	Remarks
1	Alfe-Bio	brown	457.0	d	allanite
2	Pla	colorless	5.2	c	zircon
3	Pla	"	6.2	c	zircon (black rim)
4	Pla-Pla-Bio	"	76.4	e	zircon
5	Pla	"	8.3	d	"
6	Alfe	brown	418.0	d	allanite
7	Bio-Pla	colorless	2.7	c	zircon
8	Pla	"	4.0	c	"

Taira (Tair-9) (Later granite)

No	Situation	Colour	Size	Radioactivity (Tα)	Remarks
1	Pla-Bio	pale yellow	12.2	d	zircon
2	Alfe-Bio	colorless	52.8	d	"
3	Alfe-Bio	"	270.0	e	"
4	Pla	pale brown	5.6	a (20.6)	
5	Qtz-Bio	{pale greenish brown	111.0	d	allanite
6	Pla-Bio	brown	348.0	d	"
7	Pla-Mus-Bio	"	1800.0	d	"
8	Pla	"	168.0	d	"

Taira (Tair-14) (Later granite)

No	Situation	Colour	Size	Radioactivity (Tα)	Remarks
1	Pla-Pla	smoky	10.9	d	zircon
2	Mag	pale brown	13.8	d	"
3	Pla-Pla	yellow (dirty)	5.6	c	"
4	Pla-Pla	yellow	12.5	d	"
5	Bio	colorless	41.5	d	"
6	Bio-Qtz	pale brown	8.2	d	"
7	Pla	colorless	5.2	c	"
8	Pla-Pla	brown	56.5	d	allanite
9	Pla-Mag	dirty	12.5	d	zircon
10	Pla	opaque	20.8	d	(massive)
11	Bio-Pla	colorless	46.0	d	zircon

Karikachi (Kar-4) (Medium granite)

No	Situation	Colour	Size	Radioactivity (T_α)	Remarks
1	Bio	colorless	1.6	c	zircon
2	Bio	dirty	16.5	c	"
3	Bio-Alfe	colorless	13.9	c	"
4	Bio	"	35.0	c	"
5	Pla-Pla	dirty	13.9	c	"
6	Alfe	"	4.3	c	"
7	Alfe-Alfe	colorless	6.3	c	"
8	Bio-Pla	yellow (dirty)	31.6	c	monazite
9	Bio	colorless	3.0	c	zircon
10	Bio	"	28.1	d	"
11	Bio	"	27.5	d	zircon (weak birefr)
12	Pla	dirty	3.6	c	zircon
13	Bio-Alfe	"	24.4	c	"
14	Bio	colorless	5.5	b (8.3)	
15	Bio	"	0.8	a (17.6)	

Karikachi (Kar-11) (Fine granite)

No	Situation	Colour	Size	Radioactivity (T_α)	Remarks
1	Bio-Mag	colorless	6.3	d	zircon
2	Alfe-Mag	opaque	—	d	
3	Pla	pale green	8.2	d	zircon
4	Bio-Mag	colorless	16.5	d	"
5	Qtz-Bio	"	5.2	c	"
6	Hor	"	0.6	c	"
7	Bio-Alfe	"	0.7	a (14.30)	
8	Mag-Bio-Alfe	"	10.5	d	zircon
9	Mag-Bio-Alfe	"	19.0	d	"
10	Mag	brown	27.4	d	"
11	Mag-Qtz	colorless	8.8	c	"
12	Alfe	pale brown	8.0	d	"
13	Pla (zoned)	colorless	5.3	d	"
14	Pla-Qtz-Hor	dark brown	625.0	d	allanite
15	Mag-Alfe	brown	10.5	c	
16	Mag	colorless	5.3	c	zircon
17	Mag-Bio	"	1.3	c	"
18	Pla	"	2.0	c	"
19	Bio-Alfe	"	4.3	c	"
20	Alfe-Qtz	opaque	1.6	c	
21	Alfe-Alfe	red	18.7	c	
22	Alfe-Alfe	brown	137.0	d	allanite
23	Alfe-Mag-Bio	pale brown	8.2	d	zircon
24	Bio-Qtz	colorless	0.6	b (7.75)	
25	Mag-Qtz	"	1.0	c	zircon
26	Bio-Alfe	"	29.5	c	zircon (2 pcs)
27	Pla	opaque	—	d	(decomp)
28	Qtz	smoky	2.0	b (6.20)	
29	Mag-Bio-Qtz	colorless	13.8	d	zircon

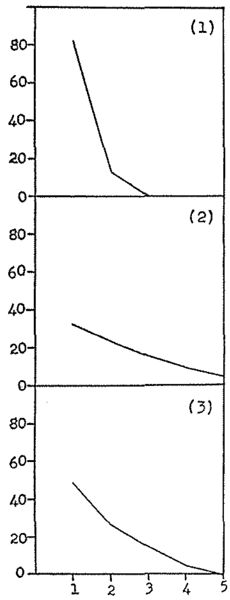


Fig. 3-1
(1) Kasagi granite
(2) Yagiu granite
(3) Nara granite

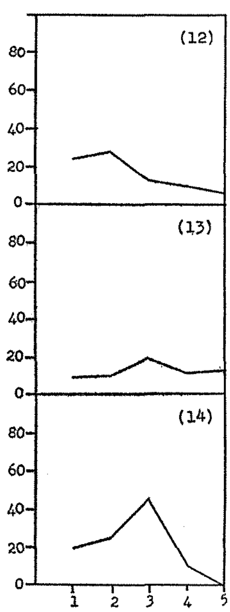


Fig. 3-3
(12) Hoki granite
(13) Mihoro granite
(14) Mihoro quartz porphyry

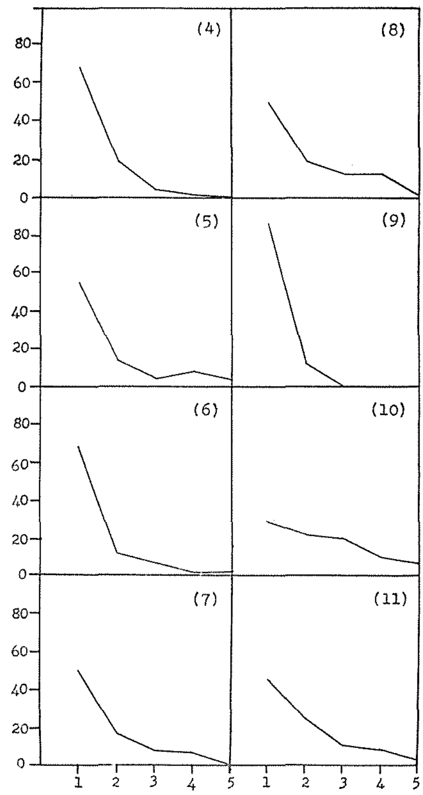


Fig. 3-2
(4) Hiei granite (8) Taira (older) granite
(5) Kirihata diorite (9) Taira (younger) granite
(6) Tarumi granite (10) Karikachi (medium) granite
(7) Sendaiji granite (11) Karikachi (fine) granite

Fig. 3 (1-3)
The relation between the radioactivity and the number of radioactive accessory minerals in granites, abscissa denotes the radioactivity in T_{α} 1-5 and ordinate the percentage of mineral grains.

2) B *type*

The percentage in number of mineral grains with T_α less than 1.0 is about 30, and the percentage gradually decreases with the increase of T_α (Hyperbola type). This type is seen in the granites of Yagiu, Hoki, Karikachi Mihoro and Gyojayama. These granites indicate rather high values in distribution density, and are usually fine grained and rather porphyritic in texture, they are distributed in small areas and are considered to have been eroded shallowly.

3) C *type*

This is an intermediate type of the above described two, and is seen in the granites of Hiei, Kirihata, Tarumi, Sendaiji, Nara and the older granite of Taira. These are medium grained granites and show the moderate values in distribution density except Tarumi.

Of course, these three types are not always conclusive, and one gradually alters to the other types. Thus the granites of Hiei and Tarumi show a tendency similar to type A, and the fine grained granite of Karikachi to type B.

Hitherto, it has been admitted that the radioactive minerals or elements are densely contained in the marginal zone of granite[6,15,16,17,18], and this is, as it were, the variation in their horizontal distribution in one granite mass. It seems that the vertical differences in the distribution of radioactive accessory minerals or elements are much more remarkable than the horizontal ones, and these radioactive minerals and elements are more likely to assemble to the apex parts of the granite intrusives than the lateral margin.

These granites, now under consideration, are various in type, however, it can be presumed that granite masses of type A have been deeply eroded, those of type B shallowly eroded, and those of type C are the intermediate of the two.

2. THE RELATION BETWEEN THE RADIOACTIVE ACCESSORY MINERALS AND THE MAJOR CONSTITUENT ONES*

The principal points concerning the radioactive accessory minerals and their distribution in the major constituent ones in granites are as follows:

1) *Radioactive accessories included in biotite are small in amount*

The grains of the radioactive accessory minerals included in biotite are 19.1 percent in number, on average of 15 granites which are in the range of 7.3–26.6 percent; and 5.9 percent in volume on average of 15 granites which also are in the range of 1.8–19.4 percent. This fact means that the radioactive accessories included in biotite are usually minute in size. The average content of biotite in these granites is 7.71 percent in volume and so these radioactive accessories can be said not to have so high association ratio[19] to biotite (less than 1). In the medium grained granite of Karikachi, the radioactive accessories have rather high association ratio to biotite, and this is partly due to the lack of allanites as in the case of the Gyojayama granite, and even in these cases more than 80 percent in volume is situated except in biotite.

* This includes the data from the granite of Gyojayama, Kyoto Prefecture[3].

2) *The amount included in feldspar and quartz is small*

The radioactive accessory minerals included in felsics attain to 24.2 percent in number and 11.1 percent in volume on the average, and this means that those included in felsics are also minute in size. In this case it is noticeable that they are situated frequently on the cracks or veinlets developed in these felsics. The association ratio to felsics is far smaller[20] as the average volume of felsics in these granites is 88.79 percent.

3) *Radioactive accessories situated on the boundaries of essential grains are abundant*

As the volume of other component minerals except the biotite and felsics, is very small in the granite, it may be concluded that a great deal of the radioactive accessory minerals lie on the boundary of the principal component minerals, in fact, they amount to 53.5 percent in number and 82.3 percent in volume. Considering the minerals lying along the cracks and veinlets in the grains of the essential minerals, these values would be still larger. And this fact indicates that those radioactive accessories situated on the boundary have a tendency to be larger in grain size.

4) The radioactive accessory minerals included in the biotite are inclined to be distributed more densely on the periphery of the latter.

5) The radioactive accessory minerals included in the bended biotite are not seen to have been deformed[19].

6) Well-formed zircon and allanite are also densely distributed in the xenolithic or migmatitic part in the granite.

7) Interstitial biotite is often met with and some radioactive accessories lie on the brown veinlet connecting with the crystals of such biotite.

8) There is a correlative relation between the grain size of the essential components and that of the radioactive accessories, namely, the radioactive accessory minerals in the fine grained granites have a tendency to be finer in size, more numerous and higher in radioactivity than in the coarse grained granites.

9) Allanite is seldom included in biotite, but on the contrary, sometimes it includes biotite, plagioclase and quartz as well as apatite, and is usually idiomorphic, often shows a zonal structure. Occasionally, allanite shows corona structure at the marginal parts contacting with biotite, and these parts differ from the core in optical properties.

From a geochemical standpoint, the radioactive elements in a trifling amount as well as rare earth elements, are regarded to enter into a crystal at the last stage of the magmatic differentiation because of the large radii of their ions, and to ascend through the interstices or cracks in granite, along with silica, water and other volatile matters contained in a residual magma.

If these radioactive elements partook in crystallization at an earlier stage of consolidation of magma as has been generally considered, the radioactive accessories would segregate in the early liquid because of their large density, as metallic ores often do. But the fact is quite different. The radioactive accessories have a distinct tendency to distribute all over the granite, nay, to gather in the marginal parts or in the apex of the intrusive bodies[21]. If the theory of magmatic differentiation be granted, and the radioactive accessories be considered to be crystallized early in a magmatic history, they must be present abundantly in basic rocks consisting of early crystallized minerals[22,23,24].

The mechanism by which the radioactive accessories gather in biotite or close to biotite which is only several percent in volume in granite, is not clear[25]. In fact the radioactive accessories included in biotite are not abundant as stated above[26,27].

Based on the geochemical consideration and on the obtained data that many of the radioactive accessories situate on the boundaries between essential component minerals, and that a few are enclosed, it may be concluded that the greater part of the radioactive elements, together with the rare earth elements, enter into crystals at the last stage of a consolidation of granite, though a small amount of them may crystallize early. The interstices or cracks in already formed minerals may be weak in connection and profitable to produce the later crystals[28]. It seems to be natural to consider that these later crystallizing elements can enter more easily into the interstices, cracks and cleavages of early formed minerals than enter into and replace the highly ordered crystal lattice, and in this case the interstices between felsic-mafic may be weaker in connection than those of felsic-felsic because of the difference of physical properties.

Thus, the radioactive accessory minerals are abundantly distributed on the boundaries of the other minerals, especially between biotites and felsics. The idiomorphic form of crystals depends on the crystallization force as often observed in the porphyroblasts of metamorphic rocks. Occasionally well-crystallized allanite or zircon are abundantly contained in the xenolithic or migmatitic part of the granite as described before, and it is notable that these compositions entered into the already formed rocks and crystallized as idiomorphic accessory minerals.

Summary and Conclusion

Microscopic and autoradiographic studies of radioactive accessory minerals in granites and their positions in relation to the major constituent minerals, have led the writer to believe the following conclusions.

1) Modes of distribution of radioactive accessory minerals in granites show characteristic types according to different localities, especially to the degree of erosion of the intrusive bodies.

2) Radioactive accessory minerals contained in fine grained granite are more abundant, stronger in radioactivity and smaller in size than those in coarse grained granite.

3) Of the radioactive accessory minerals contained in the granite, more than 80 percent by volume are situated on the boundaries or in the interstices of major constituent minerals, and those included are only less than 20 percent, and even in the latter case they are not always enclosed perfectly. From these facts the writer believes that the greater part of the radioactive accessory minerals crystallized later than the other constituent minerals.

4) As to the individual granite, the radioactive accessory minerals are densely distributed in Karikachi, Tarumi and Yagiu areas, and are rather strong in radioactivity in Mihoro, Yono, Yagiu and Hoki, these minerals are mostly zircon, allanite, and partly xenotime, monazite and some minerals of strong radioactivity.

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